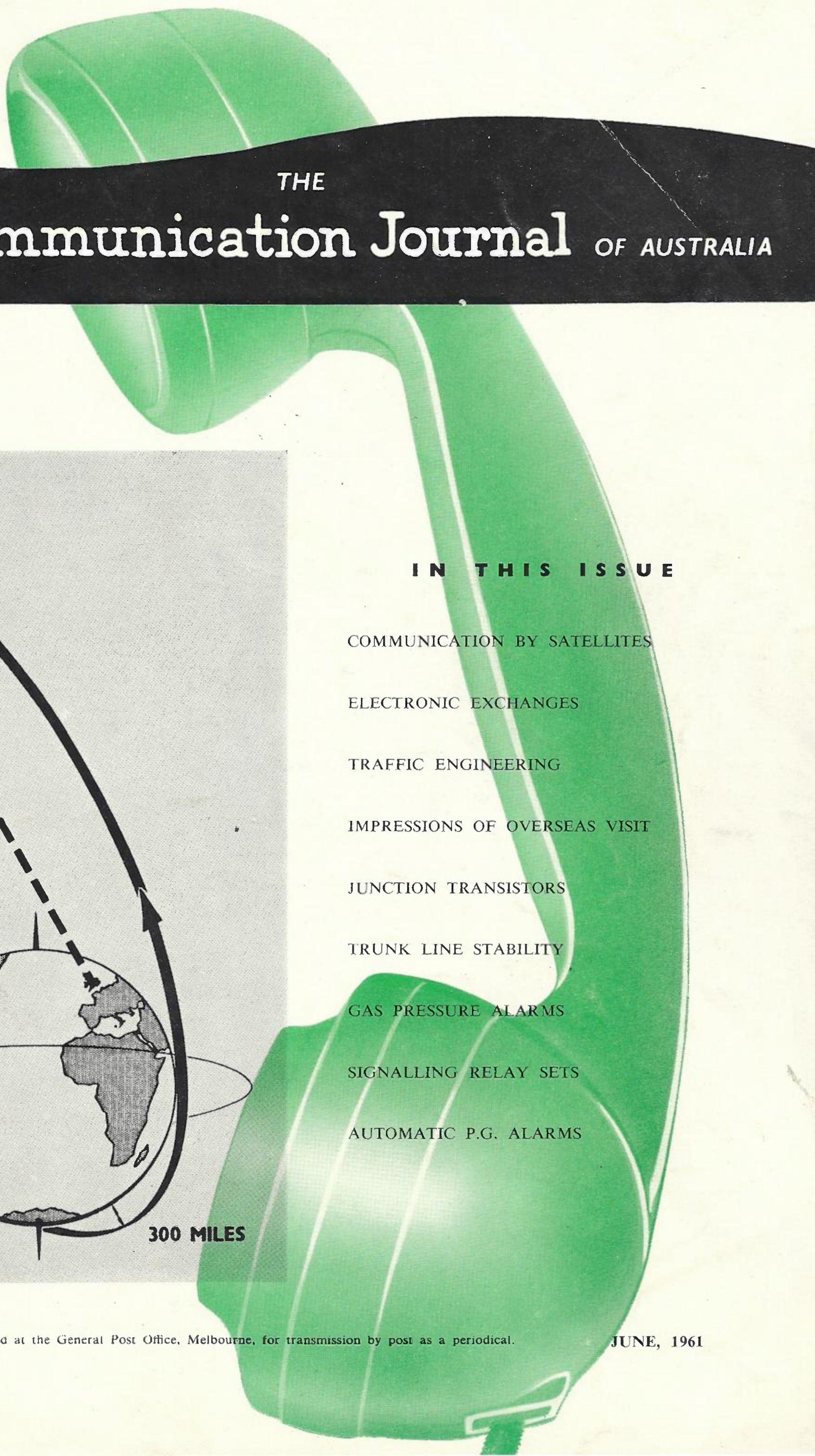
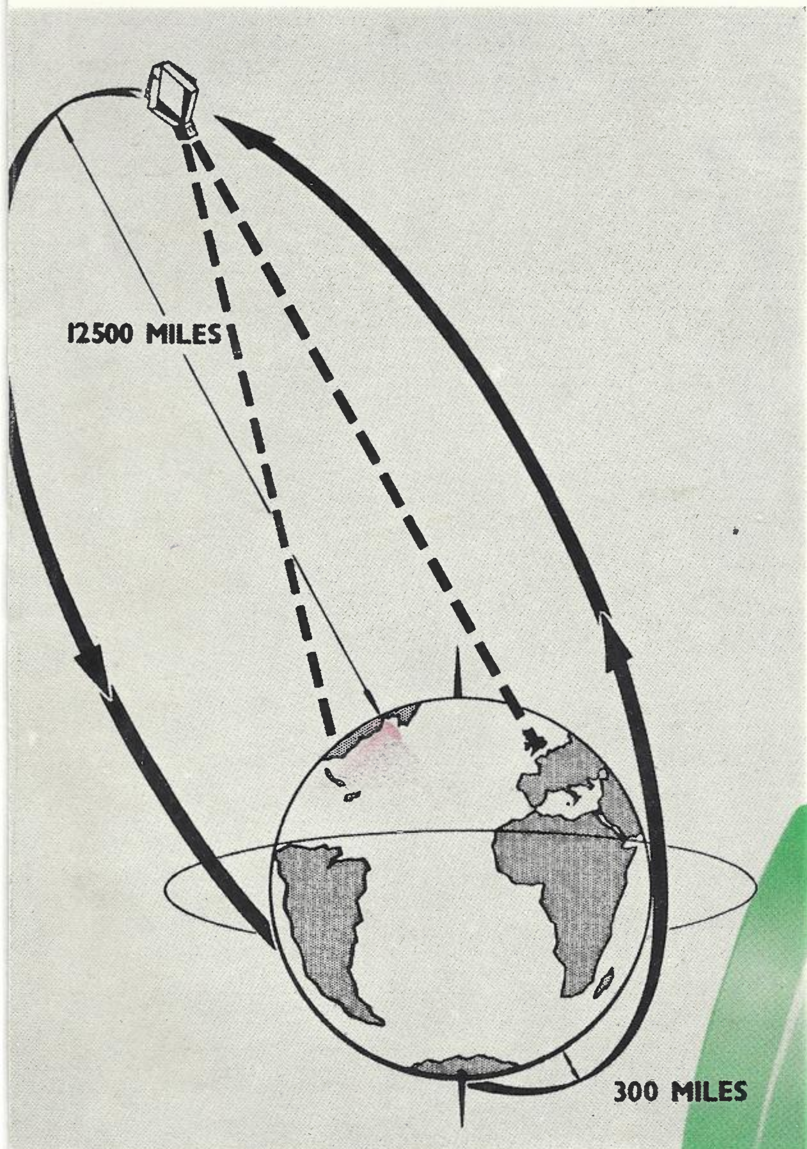
THE

Telecommunication Journal OF AUSTRALIA





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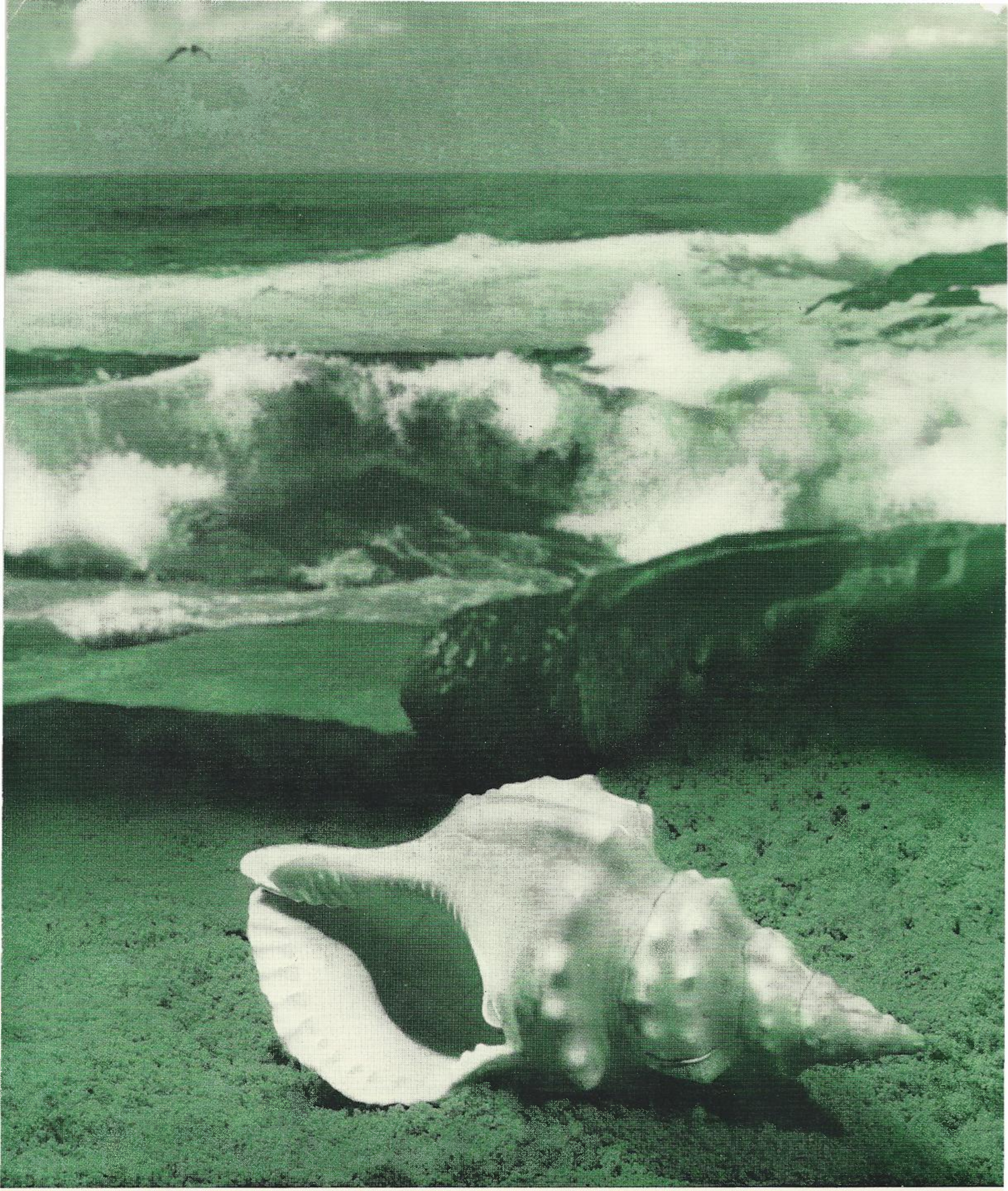

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*For addresses see page 83

RADIO COMMUNICATION BY ARTIFICIAL SATELLITES

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The Postmaster-General's Department in common with Telephone Administrations in other parts of the world is naturally very interested in the theoretical and practical possibilities of using artificial satellites for radio communication purposes. The Post Office is responsible to the Commonwealth Parliament for the provision of all public telephone, telegraph and radio communication facilities within the Commonwealth and, in conjunction with the Overseas Telecommunications Commission (which is responsible for all external telecommunications), makes provision for the connection of the public network within Australia with the networks of other countries. In carrying out its responsibilities it naturally makes use of all technological developments wherever there is a clearly established case for their adoption.

HISTORICAL

The Department is rather proud that Australia has always been quick to adapt its services to incorporate new discoveries. Most people are familiar with the fact that communication from England to Australia was inaugurated by submarine telegraph cable as far back as 1872. It will be remembered that this involved the construction of a very long and difficult section of overland pole route known to this day at the Adelaide-Darwin Overland Telegraph Route. This early effort was followed in fairly short order by submarine telegraph cables to Tasmania, New Zealand and across the Pacific to other countries.

The telephone was invented by Alexander Graham Bell round about 1876 and was adopted by Australia very shortly afterwards, at first for local exchange service and the first telephone trunk line between Hobart and New Norfolk in Tasmania was erected as early as 1888. Sydney and Melbourne were conected by telephone as far back as 1907. The invention of the thermionic valve and other important contributions made it possible to extend the range of communication both for telegraph and telephone purposes at a very rapid rate. Some of these new techniques such as amplifying valves were added on a limited scale to even some of the oldest of the submarine telegraph cables, many of which are still giving good service.

The overseas telegraph cables were supplemented by high frequency radio telegraph systems some years ago. Earlier proposals had been made for communication between England and Australia by low frequency radio methods. These, however, involved the use of a number of intermediate repeating stations and the total cost would have been rather high. The work of Marconi and other prominent workers in this field demonstrated that high frequency radio communication without intermediate repeaters was a practical and commercial proposition. The so-called Beam Wireless Service was therefore opened at a comparatively early date and considerably assisted Australia in trade, commerce and culture by improving the flow of communication at reasonable rates. Similar radio telegraph services were subsequently added to quite a number of other countries.

Radio telephone service was added to the Beam Wireless Service at a later date between England and Australia and gradually the whole telephone network within this country has been brought within reach of the overseas radio telephone link and through it to most of the world's telephones.

Although the service given by the Beam Wireless links for telegraph, telephone and facsimile services has been of great value to the countries using it, it has been known for some years that the limitations imposed by nature would prevent a perfectly satisfactory service ever being given. While it would not be correct to rule out the possibility of further discoveries being made which might improve the present techniques used in high frequency radio methods, it does seem clear that with the present state of our knowledge further substantial improvement is unlikely.

The limitations briefly are those due to the nature of the ionosphere which is a very variable means of reflecting radio waves. The variations give rise to fading and distortion and other effects which make it impossible to produce either a telegraph or telephone service which is really comparable with the performance given easily by modern land-line or cable systems. For example, it is also almost impracticable to design an H.F. radio system with multiplex facilities for more than about four telephone channels.

INTRODUCTION OF PRESENT TECHNIQUES

Repeatered Submarine Cables: The production of satisfactory designs for the incorporation of undersea thermionic amplifiers in submarine telephone and telegraph cables has been watched with intense interest by communication engineers throughout the world. Early efforts in this direction were suspended during World War II and as is often the case the suspension itself probably had the effect of considerably improving the performance of the first system which finally went into commercial use. Very worthwhile improvements, for example, had been made in the production of reliable valves and associated components during the war years and therefore for the first time it became a commercial proposition to lay cables which incorporated amplifiers to lie on the bottom of the sea without attention for many years. Once the reliability of this undersea repeater was established, it became possible quickly to adapt for submarine cable use the same amplifying principles and the same multiplexing principles which had proved so successful in every part of the world on overhead land-lines or in buried land cables. Briefly, these techniques make it possible to carry many separate telephone and telegraph messages on a single conductor. The separation between individual channels is adequate at all times, i.e., the cross-talk and noise produced in one channel from any other channel or groups of channels meets the standards which are laid down by international expert committees to meet commercially acceptable limits. The variations in volume and articulation with time are also maintained within very narrow limits.

In simple terms, the modern carrier systems of communication furnish a thoroughly satisfactory standard of performance with a steadily decreasing cost per channel mile. These cost reductions are made possible by many separate innovations, notably the mass production which is now such an essential feature because of the large scale utilisation of carrier. The introduction of transistors and of various automatic regulating devices have also contributed notably to the reduction in first cost and in annual charges. The application of such high grade engineering design to submarine cables thus results in the provision at quite competitive costs of multi-channel cables capable of carrying from 12 to 120 channels with current designs.

The use of these new techniques on the Trans-Atlantic route has already demonstrated that the high frequency radio telephone channels at least are now finding the new competition a very difficult one. The absence of fading and of noise and distortion so characteristic of high frequency radio telephone conversations has really brought about a new era in world-wide communication. Within each Continent the rapid introduction of multi-channel carrier systems has gone far to remove the old rather arbitrary distinction between local calls and trunk line calls. Most countries have already gone a long way by extending local call areas in order to take advantage of the economic savings which are now made possible by the relatively cheap provision of multi-channel systems. The submarine repeatered telephone cables promise to do in the international sphere what has already been done within each Continent, i.e., to make it possible to regard the world as a single entity in a telecommunications sense.

Evidence of this is found in the fact that places like Hawaii are now regarded as part of the nation-wide direct dialling system of the United States telephone network for the purposes of a numbering plan. Subscriber direct dialling is not yet possible, for example, between these two places but operator dialling is extensively employed and is currently

* See page 79.

being arranged also on the Trans-Atlantic route. So obvious is this development, in fact, that attempts have already been made to produce a world-wide telephone numbering plan to facilitate the rapid introduction of these submarine cables and associated signalling equipment. The importance of international agreement on such matters is obvious from the difficulties already encountered by most administrations in adapting even Continent-wide existing systems to a uniform numbering plan which will be satisfactory to the multitude of telephone subscribers who are being asked nowadays to do more and more of their own operating by dialling longer and longer series of digits from their own telephones. It is interesting to note in passing that part of this new planning has involved the United States, long regarded as a bastion of letters as well as figures on subscribers' dials, being compelled to fall into line and announce that they have already taken the first step on the road to the elimination of letters simply because of their inability to weld a combination of names and numbers into a nation-wide numbering plan, let alone a world-wide one.

As mentioned earlier, the Australian Post Office and the Overseas Telecommunications Commission have never been slow to adopt new improvements where they are clearly justified, consequently it is no surprise that arrangements were made some time ago to lay repeatered submarine cable between Australia (via New Zealand) and Canada. In Canada it will connect with the existing network within that Continent and therefore reach across to the Trans-Atlantic cables terminating on the eastern side of Canada. The first section of the new cable between Australia and New Zealand will be brought into service by June 1962. It is interesting to note that the first section of this Trans-Pacific cable will go into service on an operator dialling basis from its inception. Operators in the key exchanges in Australia will be able to dial subscribers direct in any part of New Zealand and vice versa.

Microwave Systems: The history of engineering development has shown time and time again that while the introduction of an entirely new system may appear to bring to an end one or more of the existing systems, there are many cases where, in fact, the opposite occurs. It seems almost as if a challenge is made which results in the older system being improved or modified to meet the new challenge and often it not only survives but in some cases lives to see the new rival displaced in turn. While therefore the earlier statement that H.F. radio communication systems appear to have reached the foreseeable limit in improvement is true enough radio engineers in other fields have not been idle. Intense activity has gone on in many separate fields to make better use of radio as a medium of communication. One of the significant developments has been in the use of frequencies considerably higher than the so-called H.F. band.

A great amount of knowledge has of course been accumulated over recent years in the characteristics of propagation of radio waves. Provided the sending and receiving stations are located in a direct line of sight, the ionosphere plays no part in the propagation. In this case, the transmission loss between the two points within optical distance of one another is much more constant than is the case when reflection from the ionosphere is involved. Variations in attenuation do occur but they are much more modest and can readily be taken care of by relatively simple automatic regulation devices. A second benefit of this use of optical path radio systems is the fact that very wide band-widths can readily be utilised. These wide band-widths have become possible by the nature of the propagation and by the use of a number of war-time and post-war developments. Early systems used magnetron and klystron valves and some of these continue to give good service. Developments in travelling wave tubes and many other devices have contributed to improve still further the reliability of these optical path systems. Now it is possible to take advantage of mass production of components and even of sub-assemblies, particularly the multiplexing equipment which is often the same as used for land-line carrier systems. The result has been a notable drop in cost per channel mile. The band widths are sufficient for 600 to 960 telephone channels or for television relay purposes. Systems are available with quite wide choice of simultaneous use of one or more television channels and hundreds of telephone channels. Reliability is already very high but is enhanced by automatic changeover to spare channels.

It is natural that very rapid expansion of these microwave broad band systems has taken place in all countries. The only practical limitation on the system has been the need for an optical path, but repeaters have been developed which enable two or any number of optical paths to be utilised in tandem to span almost any conceivable distance. All that is required is a relatively simple unattended repeater which picks up and re-transmits the signals received over the first optical path on into the next path and so on. Obviously, the microwave engineer welcomes the occurrence of mountain tops suitable for unattended repeating stations, provided of course they occur at about the right intervals. Much ingenuity has been expended in planning the use of sites thus provided by nature to provide networks of microwave facilities.

In some cases where nature has been unkind and the terrain is too flat to serve the microwave engineer's purposes, he has been forced to use high steel towers. These, however, are relatively very expensive although one must admit that they are capable of being placed just where they are needed and often have advantages to the maintenance engineer over some mountain sites. It is natural that engineers have thought of ways and means of beating nature by some way of elevating the repeating station high above the earth in order to extend the range of their optical paths. Captive balloons have been considered but so far have not been found practicable. Aeroplanes flying high overhead in small circles and carrying the repeaters are an obvious possibility and some years ago two of the largest corporations in the United States seriously endeavoured to sell this idea. So far, however, no commercial use has been made of this technique, though F.C.C. approval has been obtained for a year-long experiment costing $7 million to relay four television programmes from Purdue University over a service area 400 miles in diameter. The programmes will be broadcast using video tape recorders installed in the aircraft which will circle at an altitude of about 25,000 feet.

Engineers studying the behaviour of the ionosphere have naturally thought also of the possibility of artificial ionospheres and it is interesting to note that patents have been taken out at various times for ways and means of improving on nature by placing reflecting media of various kinds high above the earth. Some of these involve clouds of various substances which are known to be good radio reflectors. Even if they are dissipated over a period it is thought that replenishment would not be an uneconomical task. However, none of these devices have yet passed into the stage of commercial adoption. The facts are, of course, that the world until recently had lacked the means of placing such artificial reflecting media just where we need them.

USE OF SATELLITES

It was necessary for the development of rocket devices to be taken to its present stage before one could really see emerging a possible and at the same time practical artificial satellite for communication purposes. It is obvious that an artificial satellite is the answer to the microwave engineer's dream since it gives him a repeating station so high that his optical path becomes almost infinite (Ref. 1). It becomes possible for him to contemplate world-wide communication by one or more artificial satellites properly placed. In 1955, J. R. Pierce of the Bell Telephone Laboratories published early calculations (Ref. 2) which showed that such a scheme would be quite practicable from the radio engineering point of view. It is true, however, that only in the last two or three years has it been possible to show that rocket technology has advanced sufficiently to allow such a project to be seriously contemplated.

The modern guided rocket has already made it possible to place artificial earth satellites in orbit and while the final form of these satellites from the communications point of view is far from settled it is clear that there are a number of methods which can be utilised. Even the earlier suggestion of placing clouds of material above the earth for the purpose of reflecting radio waves has been revived because of the present-day possibilities of placing them there and maintaining them in position by rocket devices.

It is natural therefore that the Post Office and the Overseas Telecommunications Commission in Australia have followed developments of these devices with a great deal of interest and a number of studies are proceeding in conjunction with similar authorities overseas to keep abreast of possible developments in this new field. It should perhaps be emphasised very strongly that in the opinion of the people best qualified to judge in the American Telephone and Telegraph Company, in the British Post Office and in this country there is no evidence which will justify any change in the present programme of laying repeatered submarine cables between many points on the earth's surface. The reasons are obvious, in that—

(a) the techniques of the cable method are well known;
(b) the performance can be guaranteed in advance;
(c) the capital costs are accurately known as are also the annual running expenses.

On the other hand, no real information is available at this early stage on the likely costs of artificial satellite methods nor can any real guarantees be given of either initial performance or performance over a period of years.

The pressure for the provision of more telephone channels throughout the world is very great indeed and there is therefore simply no alternative but to continue with the provision of the tried and proven technique of the repeatered submarine cable to meet this current demand. On the other hand, it would be quite wrong to regard the satellite methods as necessarily being impracticable or unduly costly. Sufficient evidence is available to show that the method is promising and there is therefore a clear case for intensive research and development work in this field.

The role of a prophet is never a very happy one and it is noteworthy therefore that there are very wide variations in the estimates being put forward by various individuals as regards—

(a) the time required to produce a commercial system for either television or multiplex telephone purposes;
(b) the perforance which will eventually be guaranteed; and
(c) the cost.

It is noteworthy in the meantime that the United States Federal Communications Commission has authorised a one-year experiment in space communications, involving the launching of an earth satellite. The Bell System had recommended to the F.C.C. this one year's intensive experimental programme in order to accumulate quickly the necessary experience and design data to enable a commercial system to be evolved, based on tentative plans for a number of ground stations which will enable America to communicate with England, France and West Germany. The cost of providing the basic facilities has been estimated in one public statement at 170 million dollars. The cost of launching a single satellite of the size and weight necessary for the proposed service has been estimated at about 3 million dollars. It is hardly necessary to mention that any such figures must be regarded as extremely tentative at the present stage of development. (The initial experiment will be controlled by the National Aeronautics and Space Administration who will work in conjunction with the British Post Office and other European Administrations who will provide ground stations in Europe.)

At this stage it is important to mention that while the repeatered submarine telephone cable gives excellent service within the limits of its design parameters, it does not provide a very wide band width compared with present-day microwave radio systems. There is a very complex relationship between the size and materials of the cable, the design of the amplifying unit, the spacing of the repeaters and the overall cost which at the present time results in standard designs providing 120 telephone channels as a maximum. The complex relationship, of course, also is related to distance and naturally one finds that the system providing the larger number of channels is practicable only on the shorter distance routes. For the Trans-Pacific cable now on order 80 telephone channels will be provided. Here again, it is important to note that submarine cable equipment designers are not idle either and equipment known as Time Assignment Speech Interpolation (TASI) is being installed between England and America. This takes advantage of the fact that in an ordinary telephone conversation there are quite long intervals of silence. It is possible to stack segments of information from one channel in the idle periods of another by ingenious devices with the end result that double the number of channels can be obtained for the same overall band-width. This means that in due course when the commercial demand justifies it, it will be possible to increase the channels on the Trans-Pacific cable to 160.

Other developments having the same end result may also prove to be practicable and it is known that intensive work is going on in various laboratories in this regard. Even with all of these devices, however, the present submarine cable design does not give a band-width comparable with the band-width of a microwave system carrying, say, 960 telephone channels or one or more television channels. It is possible, therefore, that even for the relaying of television programmes or for the transmission of data or equivalent information requiring comparable band-widths, the satellite communication system may prove to be a commercial success. It is undeniable that the television industry is now a very widespread one and is growing rapidly in most countries. It is probably true that money is available in commercial circles to justify quite heavy expenditure on television relay facilities.

It is at this point, however, that it is wise to mention some conditions which may readily be overlooked. At least as far as communication on this earth is concerned the regular occurrence of night and day will be a limiting parameter for many people. Even the most enthusiastic user of the radio telephone service between England and Australia finds the novelty wears off when he must get out of bed to talk on the telephone. Similarly, the relaying of television programmes is not likely to have much attraction except on very rare and important occasions if the programme is received at a time when the people are either at work or in bed.

An examination of the world network of electrical communication, taking into account this time factor and also other well-known factors of a commercial and social character, is necessary before one can forecast likely public demand for telephone, telegraph or television services. There is a natural tendency to regard the Trans-Atlantic route as a typical one. It is undoubtedly true that here are linked together the two largest aggregations of people requiring telephone, telegraph and television facilities. The distances are within the range of likely satellite communication systems and the time factor allows quite a reasonable number of hours overlap for the use of these services without imposing hardship on one end or the other. It seems reasonably certain, therefore, that if satellite methods are to prove in on a commercial basis they will do so on this route long before they do so on any other route.

Some indication of the estimated demand for telephone communication on the Trans-Atlantic route is given in Appendix I. These estimates have been furnished by the Bell System as part of their study of future trends on this route. On other routes a careful study must be made of the time and other factors mentioned above before any sensible estimate can be made of the possible attractions of this new technique. It is clear, however, that the new method does offer the possibilities of transmitting a much wider band of frequencies than can be anticipated from present types of repeatered cables.

An extensive literature now exists on satellite communication methods. Quite a number of combinations of equipment and methods have been proposed. Some of the typical literature on this subject is found in references 3 to 12.

SATELLITE REPEATER TYPES

The satellite repeaters are of two main types — passive and active. The passive repeater exemplified by ECHO I now in orbit is an inert object and is nothing more than a large metal surface which reflects radio waves. Various configurations have been suggested such as large flat plates, corner reflectors and even clouds of half wave resonant needles. The most favoured form of passive reflector appears to be the large sphere. In the case of ECHO I it has been a diameter of about 100 feet (Fig. 1).

Present plans seem to favour active repeaters which will obviously contain much the same elements as microwave repeaters used in what are now appropriately called Earth Bound Radio Systems. The repeaters, however, must obviously be made very small and very reliable indeed. (Fig. 2.) They must also require very small amounts of power to operate them. This means that as much use should be made as possible of high gain aerials but this in turn requires that the altitude of the satellite must be controlled. This calls then for still more equipment. The performance of the complete system must depend also, of course, upon the height above the earth of the

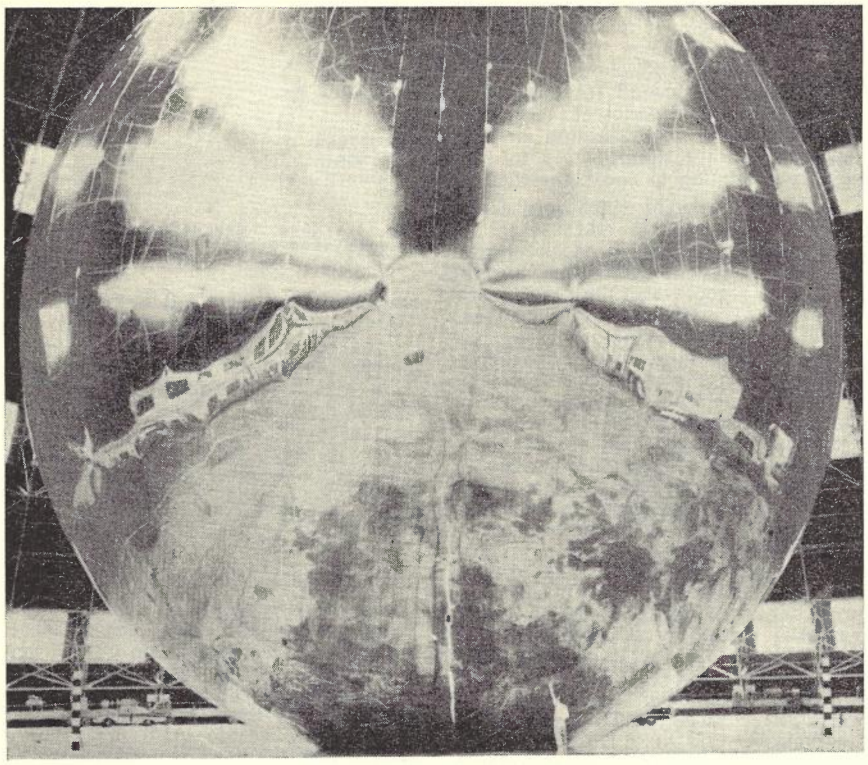

Fig. 1.—Project Echo Balloon Satellite.

repeater, on the effective power of the transmitter and on the sensitivity of the receiving devices on the ground. The performance of the system also depends very greatly on the frequency and present thinking is that the system should operate roughly between 1000 and 10,000 Mc/s. Probably, it would operate best between 2000 and 6000 Mc/s. Frequencies below 1000 Mc/s suffer from a high cosmic noise level and it is difficult to get sufficient gain from the aerials. Frequencies above 10,000 Mc/s will probably suffer from too much variation in attenuation due to rain, fog and other natural occurrences.

The outstanding advantage of the passive satellite is the fact that all costly radio equipment is on the ground (Fig. 3). It may or may not be regarded as an advantage but it is true that the passive satellite means that any number of people can use the one satellite without mutual interference (unless, of course, future history shows that phenomena at present unknown may begin to show up when a great number of transmitters bombard a single metal reflector many miles above the earth, with the signals passing through the atmosphere and the ionosphere).

The path loss (Appendix II) will probably be of the order of 250 db or higher for a passive system. This appears to make a large capacity, i.e., wide bandwidth system impracticable if reasonable standards of performance are to be achieved. The use of active repeaters reduces the path loss to figures in the region of 180 db. This makes a system with a capacity of 1000 telephone channels or one television channel possible though it is still about 40 db higher than the path loss of a typical average microwave repeater section of 35 miles as used today. It is apparently proposed to make up the difference in systems now under design by the use of very large aerials on the ground such as 60 foot diameter dishes or 50 foot square horns (Fig. 4), the use of negative frequency feedback modulation schemes and to sacrifice some of the fading margin normally allowed. Current American design figures are given in Appendix III.

Some of the problems involved in the use of active repeaters include:—

(a) the effects of high energy radiation on transistors and solar cells are known to be significant.

(b) the cooling of heat dissipating components such as valves without the presence of gaseous cooling media poses unusual problems;

(c) reliable life data on components in such an environment is not available.

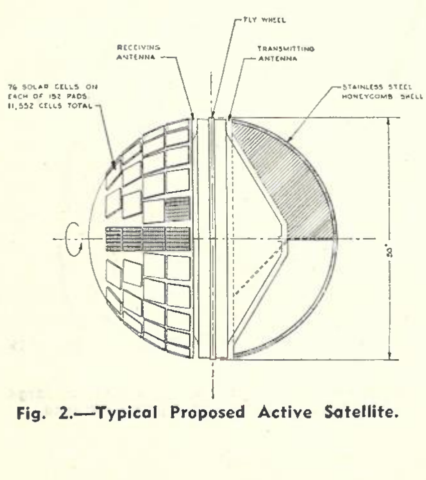

Fig. 2.—Typical Proposed Active Satellite.

Fig. 3.—Holmdel Ground Station used for Project Echo.

POSSIBLE ORBITS

Either type of satellite repeater may be placed in any orbit desired, subject to the well-known laws of mechanics. The payload capacity of the now available rockets does limit the possibilities and some compromise is essential. The optimum choice is still under discussion, possibilities being a low or high altitude circular orbit or particular forms of elliptical orbit (Appendix IV).

A circular orbit at an altitude of 1000 to 6000 miles would allow a satellite weighing up to ¾ ton. A passive reflector in this range of altitude would be practicable for some applications. The problems of transmission path delay, interference and jamming would be less serious with this orbit but there are disadvantages. The major ones are the large number of satellites required for world wide coverage (30 to 50) and the complicated steering and tracking arrangements required at the ground stations for effective use of the satellites. It is of interest that the American Bell System proposals for a world-wide system use this orbit, at an altitude of 6,000 miles.

A satellite in circular orbit at an altitude of about 22,300 miles, if launched in the correct direction over the equator, would remain stationary as viewed from the earth's surface and would be within sight of nearly half of the globe. Thus only three satellites would be required to provide communication over substantially all populated areas (Fig. 5). The payload of available rockets would restrict the repeater to a weight of 200 lbs., which is insufficient in the present state of the art. In addition, the very long path introduces a delay of ¼ second or an echo delay of half a second. Echo suppressors would be necessary for telephone communications with attendant troubles from syllable clipping. With an echo delay of 1 second (obtained on a two-hop path) experiment (Ref. 13) has shown that a conversation is sometimes completely stopped due to both parties attempting to speak together.

An important point which must not be overlooked is that in addition to the total time of propagation of speech over the satellite system itself there must be taken into account also the time of propagation over the existing networks within the terminal countries. It is possible, for example, that a particular satellite system would have acceptable delay time itself but by the time the terminal is extended within the country concerned the total delay time between two subscribers may be quite intolerable. It is hardly necessary to stress that satellite systems cannot deliver communication direct to any subscriber except possibly in military and special applications but must deliver the traffic to some switching centre in an established network. The time of propagation within a country is fixed by a complex relationship between distance, type of conductors, use or otherwise of loading coils, nature of equipment used, some of which includes delay in filters and similar components, etc. In Australia, for example, the distance from Sydney to Perth is comparable with the Trans-Atlantic crossing and any satellite system delivering traffic to Australia would certainly have to take account of the propagation time Sydney to Perth.

Elliptical orbits have been suggested in an attempt to make most efficient use

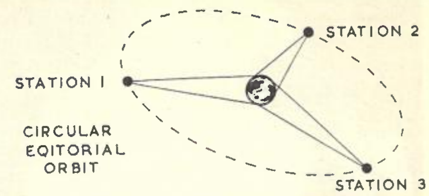

Fig. 5.—Three Satellites in 24-hour Orbit would cover populated area of the earth.

of a rocket's payload. It is thought that 700 lbs. could be placed in an orbit with a perigee height of 300 miles and an apogee height of about 13,000 miles (Fig. 6). It is characteristic of elliptic orbital systems that to an observer on the earth the satellite appears to travel slowly through its apogee and quickly through its perigee. This is advantageous in that the period of visibility between two correctly sited ground stations appears to be longer (Ref. 12).

TECHNICAL STANDARDS

The application of artificial satellites for commercial purposes such as incorporation in the P.M.G. or O.T.C. networks requires that such systems be integrated with existing services and compete economically with alternative means of providing service. Also performance standards which have evolved over many years must be met before the system can be classed as fully satisfactory.

The important property offered by this new means of communication is the ability to provide broadband bearers over ranges of up to 10,000 miles in one hop. Baseband widths of up to 5 Mc/s are envisaged at present but there is no theoretical limitation to prevent very much broader bands being possible.

Some of the factors which are being considered by the Post Office relate to what can be described under the general heading of transmission standards and

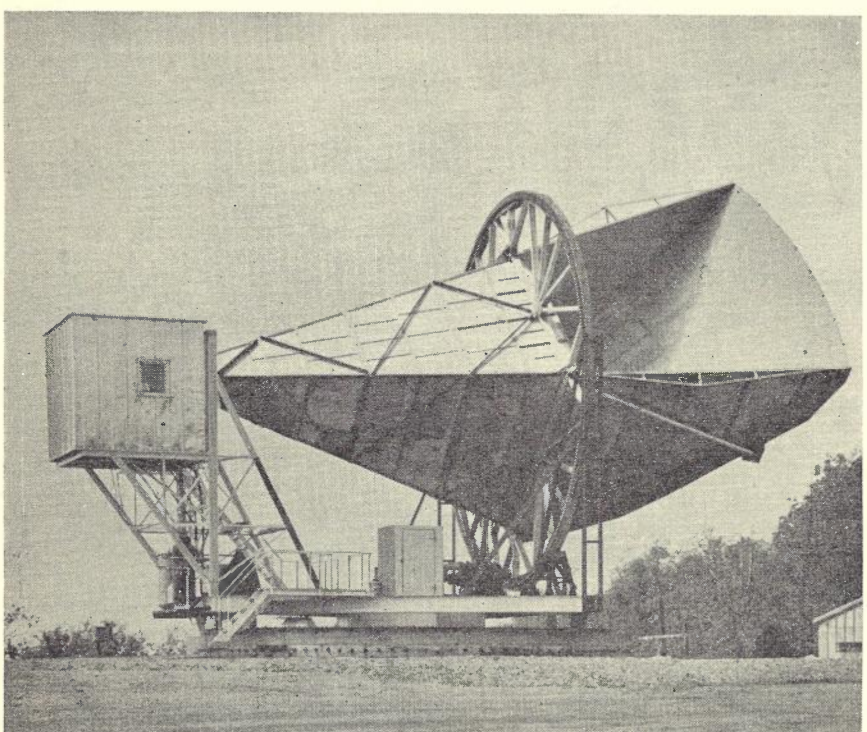

Fig. 4.—Project Echo Horn Reflector Receiving Antenna.

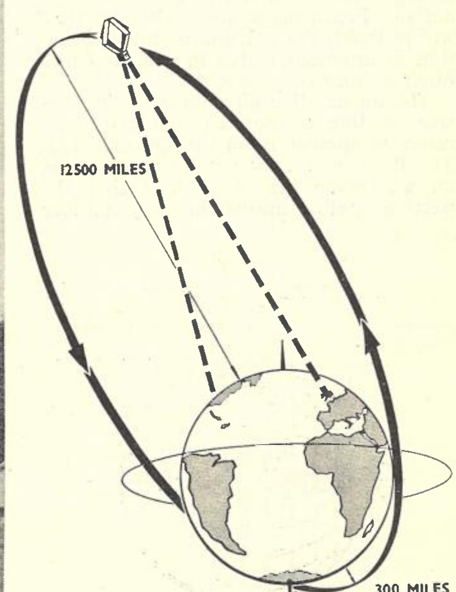

Fig. 6.—An Elliptical Orbit allows a large Satellite to Operate at a great distance.

include transmission delay, noise, bandwidth, frequency allocations, secrecy and reliability. These items will now be discussed in turn.

Transmission Delay: The problem of transmission time between terminals has been referred to in connection with synchronous (24 hour orbit) satellites. The propagation time gives a delay of about 5.4 milli-seconds per 1,000 miles of radio path length so that echo from the far end terminal is delayed by 10.8 milli-seconds for each 1,000 miles of path. Delays of more than a second could therefore be incurred and it is by no means certain that this would allow workable comercial telephone circuits to be derived.

Delay time has been considered by International Committee (CCITT) in connection with conventional means of providing service and it has been recommended that a magnitude of 250 milli-seconds one way delay time should not be exceeded. 100 milli-seconds of this is assigned to end connections so the recommended maximum delay on an international line is set at 150 milli-seconds, giving a maximum echo delay of 300 milli-seconds.

The route United Kingdom to Australia is an important one where, because of the long path length, the time delay will be large. The shortest possible loop or echo delay of 120 milli-seconds would be given by propagation along the surface at the speed of light. For comparison, the loop delay through the proposed cable via Canada will be about 280 milli-seconds. Using satellites, the delay will depend on the altitude and number of hops required. A satellite at low altitude is only visible over a comparatively small area, so that a large number of hops would be needed. The path length is therefore not much greater than the distance over the surface because the "zig-zag" path (from terminal to satellite 1; to repeater 1 on the ground; to satellite 2; to repeater 2 on the ground; and so on) is confined to a narrow strip of altitude. If, on the other hand a lesser number of higher altitude satellites are used, the path is covered in a lesser number of hops, but the total path length is longer.

For reasons such as atmospheric drag and heating, it is not practicable to consider seriously the use of very low altitudes such as say 250 miles. An additional reason against this low altitude solution is the consequential need for a large number of satellites, with a correspondingly large number of ground stations. The theoretical sites for some of these would fall in oceans or unavailable territories. A probable satisfactory altitude would be in the range 3,000 to 4,000 miles with say 4 or 5 ground repeaters employed. Adding 100 milli-seconds for terminal networks, the minimum echo delay will amount to about 0.5 and 0.6 seconds respectively, or about twice the recommended maximum for international circuits.

Noise: Practice in the Australian Post Office on noise is based on the recommendations of the appropriate international committees. For microwave bearer systems this body is C.C.I.R. which has laid down allowable noise on a statistical basis. The recommendations are not directly applicable to satellite systems but performance of this general standard will be required.

Bandwidth: The bandwidth required for a satellite communication scheme depends on the modulation system to be used. American proposals call for an R.F. band of 125 Mc/s giving 500 Mc/s per system (two assignments in each direction from the satellite). This particular system uses negative frequency feedback to improve the system's signal/noise ratio by up to 20 db.

Frequency Allocation: Any frequency not seriously affected by the atmosphere (including ionosphere) is useful for satellite communications. This puts the range from say 100 to 10,000 Mc/s with a broad optimum between 2,000 and 6,000 Mc/s. There are many services located in this band but it has been possible to repeat allocations with geographical separations of a few hundred miles so that congestion has not yet become very acute. The advent of satellite transmitters with interference potential over nearly half the earth's surface will alter this situation and serious problems are likely to arise. It is expected that this aspect will be discussed by the I.T.U. in 1963. (Appendix V.)

The converse problem of interference to the satellite system can be caused by a variety of factors both natural and man-made. Radio emissions from the sun and other objects can affect the noise performance of masers and parametric amplifiers. (Appendix VI and Refs. 14, 15 and 16.)

Another factor is thermal emission picked up from the atmosphere when the aerials are at low elevation angles (say up to 5° above the horizon).

Secrecy: No difficulties are anticipated in maintaining secrecy on satellite circuits which is as important for a public service as it is for military circuits. The standard frequency division multiplex equipment in itself minimizes accidental eavesdropping and further protection can be given using the methods developed for H.F. radio systems.

Reliability: The reliability of a satellite communication scheme depends on the separate reliabilities of the equipment and the radio path. Equipment reliability will not be known with certainty until experience has been gained with a pilot system. However when such data comes to hand, any deficiency that is apparent may be removed by straightforward engineering development.

The reliability of the radio path will depend on the number and locations of the satellites in orbit. In general a path reliability of at least 99 per cent. is necessary and a sufficient number of satellites must be available to meet this figure. About 30 satellites in a 3,000 mile circular orbit would be needed for a 2,500 mile path.

COSTS

Now a word on the economics of communication via satellites. The estimates put forward on costs are much less precise than the engineering estimates and it is certain that some of the very low charge rates which have been quoted are too optimistic. They are based only on the cost of providing and maintaining the satellites and ground terminal stations. Estimates on the cost of this bearer provision also vary widely, capital investment ranging from £50 million to £150 million with annual charges for satellite replacement from £2½ million to £19 million.

The cost for the AT and T proposed world-wide scheme is £51 million giving 600 telephony channels between terminals or if a television channel between terminals is added the cost is expected to be £76 million. Annual charges are not yet published.

CONCLUSION

The cost estimates, inaccurate though they may be, nevertheless show that the method could be economic for international communications and could supply broadband facilities not otherwise possible. Available telephone channels between continents could be multiplied by a large factor but to realise the reduction in operating costs which might be expected to result, these extra channels must be fully loaded. This problem of usage was thought to be sufficiently important to justify a serious editorial article in "Telephony" (Oct. 29th, 1960). The article advocated an immediate campaign to introduce bi-lingual education so that enough subscribers would be available to make a large number of international trunk circuits pay. It must be emphasised however that the success of such telephone channels depends on a solution being found to the time delay problem. Subscribers will not be attracted to a service which does not allow natural conversation but instead requires unusual operating procedure similar to that necessary on "press-to-talk" equipment.

New services, not otherwise possible, can result from satellite relay systems. Television relaying is probably the most important of these and an international network of high quality is quite practicable. High speed data transmission will also be possible and indications are that this class of traffic will increase greatly in the future.

At this stage it does not seem possible to consider seriously the broadcasting of television programmes to individual homes by satellite means. With passive satellites it may be physically possible using Megawatt transmitter powers and refined receivers with steerable aerials, but such a complicated domestic installation would not be likely to be acceptable. The aerial and receiver for ordinary homes must be assumed to be simple and with this restriction, transmitter powers are not yet available for use in active satellites to provide a satisfactory grade of service. (Appendix VII.)

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APPENDIX I

FORECAST OF GROWTH — TRANS-ATLANTIC ROUTE

To illustrate the views of a responsible section of the American communications industry, some published information (from Ref. 7) has been reproduced below and in Appendices III and V.

"Significant figures in forecasting future demand across the Atlantic are as follows:

The population of United States has increased about 60% since 1920 but the telephones in use within that Continent have increased by more than 5 times. The increase, in fact, is from some 13 million to over 70 million telephones. Outside the United States the increase has been of a similar order. The telephones have increased from 7 million in 1920 to about 62 million in 1960, an increase of almost eight times. By contrast, although there has been a tremendous upward surge in world population of about 1,000 million people, this represents only an increase of 60%.

Another significant figure is the increase in the number of telephone conversations. In the United States they increased by five times from 1920 to 1960. The really significant figure, however, is the increase in the number of trunk line conversations as distinct from the total. In the period 1920 to 1960 the trunk line calls increased from 16 million to over 532 million, i.e., an increase of over 3,000%. This gives important evidence of the trend for people to speak over steadily increasing distances more and more frequently as part of the growth of a country. Overseas radio telephone service was established in U.S.A. to England about 1927. The number of messages increased from 11,000 in 1927 to over 3 million in 1960. When the first repeatered submarine telephone cable was placed in service the traffic to England increased 90% in one year. Similarly messages to Alaska and Hawaii have increased about 75% and by 80% respectively since repeatered cables were laid to these places.

In forecasting future growth it is obvious that an important factor is the relatively small use of the telephone in countries outside the United States. If even a few of these countries progressively increased the number of telephones per capita to figures similar to those now applying in the United States, it is evident that the future demands for inter-Continental communication would be very great indeed compared with present-day usage. It is anticipated, for example, that the telephones in the United States would increase to 235 million by the year 1980 and that trunk line calls will increase to about 2,500 million by the same year. There is no doubt that telephone growth in many undeveloped countries is now showing signs of at least approaching some of the earlier figures of the United States. Taking even a conservative view there seems little doubt that there could be 265 million telephones outside the United States by 1980. This is based on a figure of only seven telephones per 100 of the population. Adding the 235 million anticipated for the United States gives a possible world total of 500 million telephones in 1980.

Experience in the United States has shown that close co-relation has existed between the number of telephones, the number of trunk line calls and the population at various years. As undeveloped countries become more industrialised it is a fair assumption that the same factors which led to a demand for telephones in the United States would be at work in these other countries. The overseas calling rate per 1,000 world telephones for calls between the United States and overseas points increased from 7 to 25 between 1945 and the present time. The trend of these curves shows that a figure of 200 calls per 1,000 world telephones by 1980 would be a reasonable forecast. This indicates that by 1980 it would be necessary to handle about 100 million overseas calls. In fact, this estimate seems to fit remarkably well with the trend of the curves applying from 1927 to that of 1960. It would be necessary to provide about 10,000 channels to handle this amount of traffic in 1980. When telegraph, data transmission and special military and other private line services are taken into account, it seems that at least 12,000 channels would be necessary by that year. The American authorities estimate that of this total of 12,000, it would be necessary to terminate about 3,500 in Great Britain and Central European Area. It should be emphasised, of course, that none of these calculations take television into account. As a matter of general interest, the foregoing figures approximate to about 50 telephone cables of the type now currently being installed."

APPENDIX II

PATH ATTENUATION FOR PASSIVE AND ACTIVE REPEATERS

The radio path attenuation is considered below in terms of the loss between isotropic aerials. Thus aerial gains, feeder losses, etc., must be included with the path loss figure to obtain the attenuation from transmitter output to receiver input terminals.

For satellite communication systems the aerial gain factor will be large and most conveniently calculated in terms of the effective aperture area. The relation is:—

Gain over an isotropic aerial (in db) $= 10 \log (4\pi A/\lambda^2)$

Where $A =$ Effective area of aerial aperture (usually between one half and two-thirds of the actual area).

$\lambda =$ Wavelength.

Consistent units (sq. metres and metres or sq. ft. and feet, etc.) must be used in the above. Fig. 7 shows the aerial gain in terms of the above relation.

The path conditions are different depending on whether passive or active satellites are used. The two cases are therefore treated separately below:—

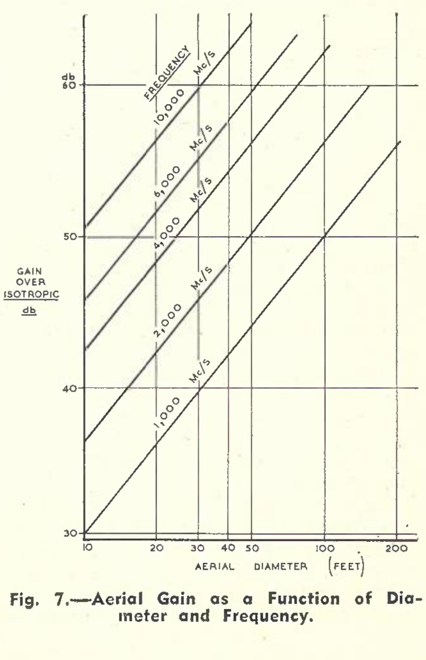

Fig. 7.—Aerial Gain as a Function of Diameter and Frequency.

Passive Repeaters: In this case the path loss is considered between isotropic aerials at the transmit and receive ground terminals and the attenuation calculation must therefore include the effect of the reflector performance. The reflecting properties of many possible types of passive repeater have already been evaluated for radar purposes so the standard radar equation may be used to work out the path loss. In the case of a spherical reflector, which is the type most likely to be used, it is convenient to use the equation:—

Path Attenuation between isotropic aerials (in db)

$= 20 \log (16\pi d_m^2/\lambda D)$

where d_m = geometric mean of the distances between the satellite and the two terminals,

and D = Diameter of the satellite.

All quantities must again be in consistent units.

Fig. 8 shows this relation over a typical range of conditions.

As an example, consider a satellite of 100 ft. diameter located at a distance of 1,000 miles from one terminal and 2,250 miles from the other. The geometric mean distance = $\sqrt{1{,}000 \times 2{,}250}$ = 1,500 miles and let us say the frequency is about 1,000 Mc/s giving a wavelength of 1 foot. The path loss is then:—

$20 \log (16\pi (1{,}500 \times 5{,}280)^2/1 \times 100)$
$= 270$ db.

If ground aerials of 60 ft. effective diameter were used in conjunction with this satellite each would provide a gain of about 45 db so the attenuation from transmitter to receiver, ignoring feeder and filter losses, etc., would be around 180 db.

Active Repeaters: In this case, each section of the path is considered separately and the attenuation worked out from the transmit terminal to the satellite and then from satellite to ground receive terminal. The methods familiar in connection with conventional microwave systems are used, the relation for propagation in free space being:—

Path Attenuation between isotropic aerials (in db)

$= 20 \log (4\pi d/\lambda)$

where d = length of path under consideration.

Distance and wavelength must be in the same units.

This relation is plotted in Fig. 9.

For an example, let us assume an active satellite at 22,000 miles distance and as in the example of the passive satellite above, a wavelength of one foot. The path loss is then:—

$20 \log (4\pi (22{,}000 \times 5{,}280)/1)$
$= 183$ db.

If the same 60 ft. (effective) diameter aerial were used at the ground terminal and the satellite aerial were equal in gain to an isotropic aerial an aerial gain improvement of 45 db would be expected. The attenuation from transmitter to receiver would therefore be about 138 db.

Comparison of this result with that obtained from the passive repeater example illustrates the justification for intensive research and development to make a reliable active repeater.

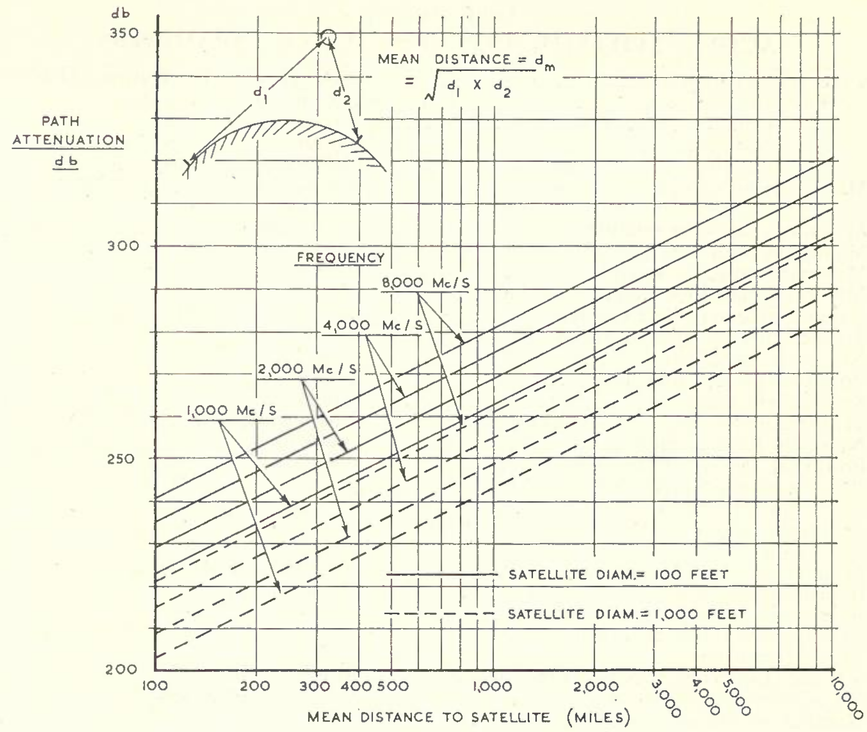

Fig. 8.—Path Attenuation as a Function of Distance and Frequency for Passive Satellites.

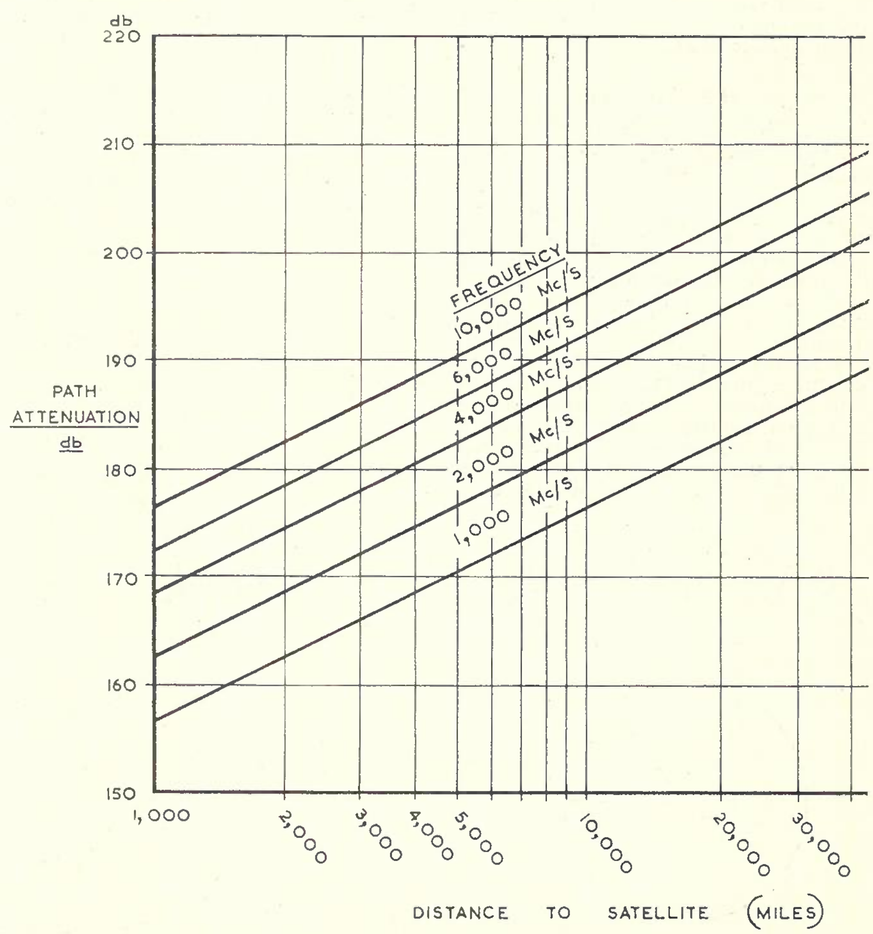

Fig. 9.—Path Attenuation as a Function of Distance and Frequency for Active Satellites.

APPENDIX III
ACTIVE SATELLITE REPEATER SYSTEM PARAMETERS

Experimental Path	USA (Holmdel)—Europe (Paris)
Satellite, altitude	2500 miles
orbit	circular polar
period	2 hours 55 minutes
velocity	14,450 mph (4 mps)
Mutual visibility time, best pass	approx. 30 minutes 7½° above horizon
Maximum range to satellite	4600 miles
Maximum path loss	130 db
Minimum range to satellite	2500 miles
Minimum path loss (reference value)	125 db
Ground antenna effective area	1700 ft^2 (60' dish)
Temperature of ground receiver	30° Kelvin
Noise in 10-mc band	—144 dbw
Power of ground transmitter	1 kw
Satellite antenna	Isotropic — 3 db
Temperature of satellite receiver	3000° Kelvin
Noise in 100-mc band	—114 dbw
Power of satellite transmitter	1 watt
With satellite at MAXIMUM RANGE:	
Margin relative to system objective	— 1 db
Margin above FMFB threshold (C/N = 12 db)	2 db
Modulation	large index FM
Improvement	21 db
Baseband	5 mc
R-F spectrum (30 db down)	104 mc
Radio frequency	6 kmc
S/N for TV, p.t.p. signal to r.m.s. noise	48 db
Noise in message channels	38 dba at zero level
Number of message channels	600

Since the above figures were published, advice has been received that the proposed satellite altitude has been altered to 6,000 miles. This is to avoid one of the maxima of the Van Allen radiation belts which has been found to occur at about 3,000 miles altitude.

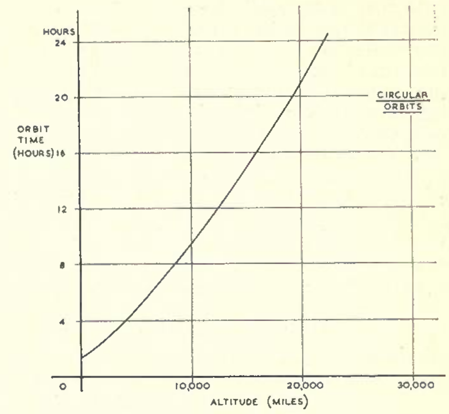

Fig. 11.—Orbit Time as a Function of Altitude for Circular Orbits.

APPENDIV IV
ORBIT CONDITIONS

At the altitudes of interest for communication purposes, the only force acting on a satellite is due to the earth's gravitational attraction. The satellite is therefore constantly falling towards the centre of gravity of the earth and since the mass of the satellite is completely negligible compared with the earth's mass, the earth may be considered to be stationary.

Referring to Fig. 10 assume that the satellite is propelled horizontally from A with a velocity v. (The function of the rocket and guidance system is to provide this initial impetus in the correct direction.) If the velocity is of the correct value, after any given time, such as when the satellite has reached position B, the satellite will have fallen a distance which exactly compensates for the curvature of the earth and will be in a stable circular orbit. We may therefore equate the acceleration of the satellite towards the centre of the earth (centripetal acceleration) with the constant acceleration due to gravity and this allows the orbit time to be easily calculated.

If r is the distance from the earth's centre to the satellite, the centripetal acceleration $= v^2/r$.

The acceleration due to gravity is inversely proportional to the square of the distance from the earth's centre, so taking the conventional surface value of 32.2 ft./sec./sec. the acceleration due to gravity at the satellite $= 32.2\ R^2/r^2$ (where R is the radius of the earth).

Thus $v^2/r = 32.2\ R^2/r^2$ ft./sec./sec.

(R & r in feet)

so $v = 5.7\ R/\sqrt{r}$ ft./sec.

It is convenient in calculations to express the distance to the satellite in terms of ratio to the earth's radius so, converting the units to miles and seconds

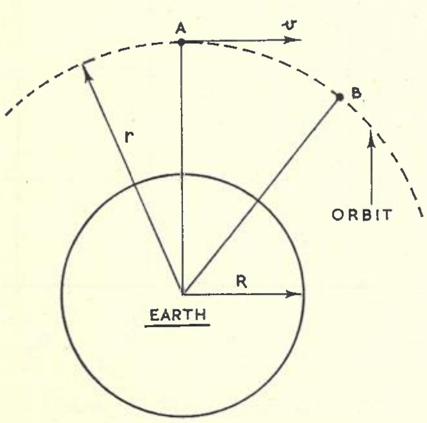

Fig. 10.—Calculation of Orbit Time for Circular Orbits.

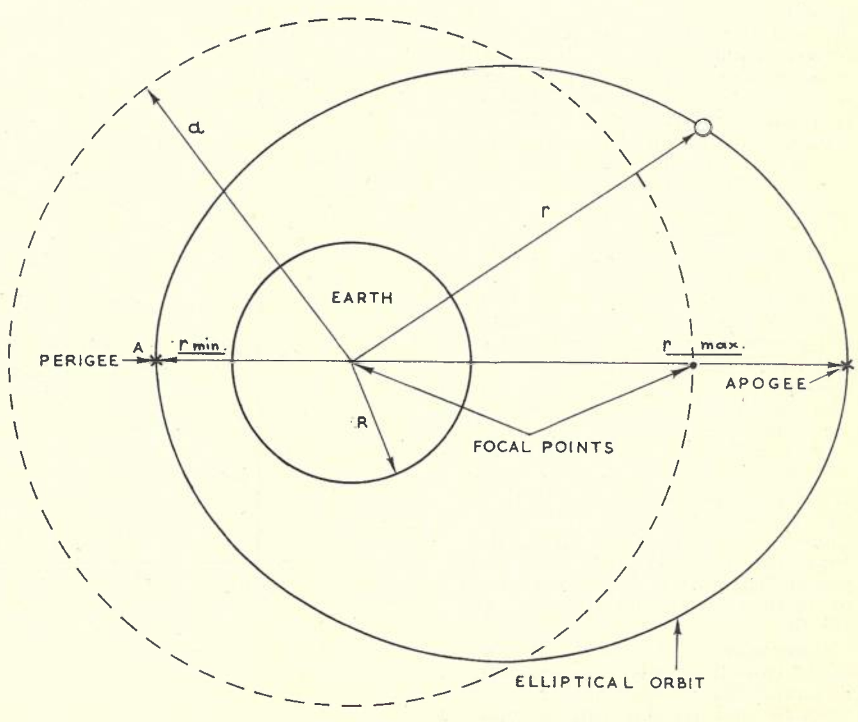

Fig. 12.—Calculation of Orbit Time for Elliptical Orbits.

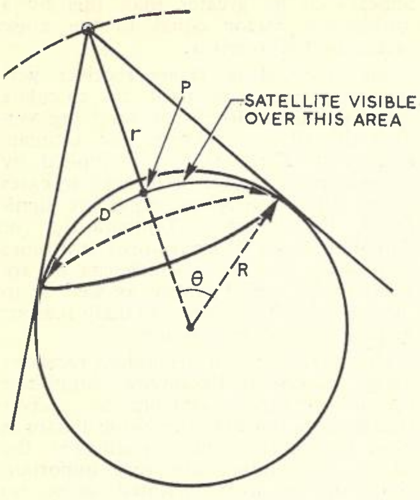

Fig. 13.—Calculation of Area Visible from Satellite.

and using a value for R of 3,960 miles the velocity may be written as

$v = 4.91 \sqrt{R/r}$ miles per second . . (1)

The distance around a circular orbit is given by $2\pi r$ so the orbit time, T, may be calculated by dividing this distance by the velocity. The result is:

$T = 1.34 r^{3/2}/R$ minutes

or $T = 84.4\ (r/R)^{3/2}$ minutes . . . . (2)

Fig. 11 shows orbit time as a function of altitude for circular orbits.

If the initial velocity of the satellite at A in fig. 10 differs from that required at the altitude of A to ensure a circular orbit one of three things will happen. If the velocity is much too low, the satellite will spiral down to earth and fail to go into any repetitive orbit. On the other hand if the velocity is higher or slightly lower than required for a circular orbit, the satellite will move in a stable elliptical orbit. For the higher velocity, point A on the figure, where it has been assumed that the initial impetus is given, will become the perigee (point nearest to the earth) while the apogee (point furtherest from the earth) and the two focal points of the ellipse will be located as shown in Fig. 12. For the lower velocity, the perigee and apogee will be located opposite to those shown on the figure.

The velocity of the satellite will vary around the orbit in accordance with the law of Kepler which states that the radius vector (r) sweeps out equal areas of orbit in equal times. The extent of the variation depends on the eccentricity of the ellipse which is defined by the equation

$e = (r\ max. - r\ min.)/2a$

where $a = (r\ max. + r\ min)/2$ which is the average distance of the satellite from the earth's centre. The velocity at any point and the orbit time can be easily calculated by introducing this average distance into equations 1 and 2, the results being:—

Velocity $v = 4.91 \sqrt{(2\ R/r) - (R/a)}$ miles/second . . . . (3)

and Orbit Time $T = 84.4\ (a/R)^{3/2}$ minutes . . . . (4)

Visibility time: For communication purposes it is necessary to know the distance and time over which a satellite is visible.

The distance over which the satellite is visible at any time is a circle on the earth's surface centred immediately below the satellite (at the "sub-satellite" point P), as shown in Figs. 13 & 16. The diameter of this circle is the section of great circle D whose length is given by $2R\theta$ where θ is the angle in radians subtended at the earth's centre as shown. Thus the diameter

$D = 2R \cos^{-1} (R/r)$ miles . . . . . . (5)

where r and R are in miles and $\cos^{-1} (R/r)$ is in radians.

Thus the diameter D depends only on satellite altitude and the variation with this is shown in Fig. 14.

The time a satellite is visible over any point on the earth's surface depends on where the point is situated relative to the movement of the centre of the circle shown in Fig. 16 and the velocity and altitude of the satellite. The time will be a maximum when the centre of the circle passes through the point, i.e. when the satellite passes directly overhead. For circular orbits, where the velocity and altitude are constant, this maximum duration of visibility is shown as a function of altitude in Fig. 15.

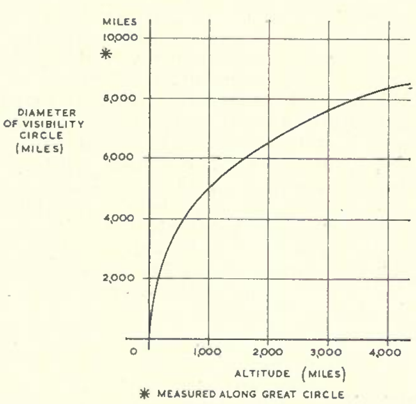

Fig. 14.—Diameter of Visibility Circle as a Function of Altitude.

If the centre of the circle does not pass through the point it is only during a portion of the maximum period that the satellite will be visible as shown on the plan diagram in Fig. 16. Consider first the point shown at A. The satellite will be visible from this point for the proportion of the maximum time that the chord CC is to the diameter of the circle or,

$$\text{Duration of visibility} = \text{Maximum duration} \times \frac{\text{length (A1 to A2)}}{\text{length (D1 to D2)}}$$

The more interesting case is where two points, such as A and B, must communicate via the satellite. This can only happen when A and B see the satellite simultaneously so the above procedure must be applied twice. Thus A sees the satellite when the sub-satellite point is located between A1 and A2 while B sees the satellite over the range B1 to B2. The common visibility range in this case is A1 to B2 so Duration of Common Visibility = Maximum duration

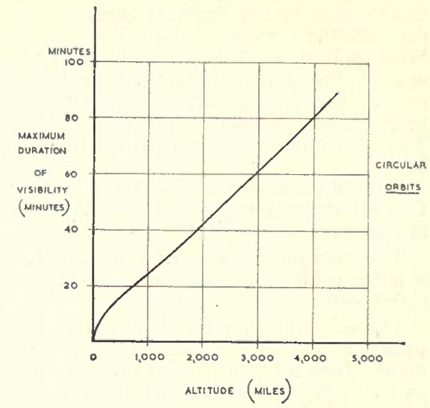

Fig. 15.—Maximum Duration of Visibility as a Function of Altitude for Circular Orbits.

$$\times \frac{\text{length (A1 to B2)}}{\text{length (D1 to D2)}}.$$

The above simple theory is adequate to assess the suitability of an orbit for a particular communication system but to allow estimates of the number of satellites required for any system and to appreciate the advantages claimed for particular elliptical orbits, it is necessary to consider the major perturbations to be expected.

Orbit Perturbations: It has been assumed above that the earth is a perfect homogeneous sphere so that the gravitational attraction is constant anywhere at a given radius from the centre and that drag due to the atmosphere is negligible. At the altitudes of interest for communication satellites (1000 miles and over) the second assumption is permissible even though the air drag is increased greatly by a retarding effect due to electrified particles, but gravitational variations do have a marked effect on the satellite's motion.

The earth is markedly flattened at the poles the dimensions being (ref. 17)

Equatorial radius = 3963.18 miles

Polar radius = 3949.89 miles

This polar flattening, or as it is more often termed, the equatorial bulge, causes a variation in gravitational force from equator to poles and is the most important perturbing agency being some 10,000 times more effective than the gravitational forces due to the sun and the moon. The effect is to impress two distinct motions on the orbit as described below. Terms to be used are indicated in Fig. 17.

In the absence of the equatorial bulge the plane of the orbit would remain fixed in direction and the earth would rotate around its axis as shown once per day. Each successive pass of the sub-satellite point would be located westward on the earth's surface from the preceding one by the number of degrees of longitude corresponding to the orbit time (15° per hour).

The first effect of the equatorial bulge is to cause the plane of the orbit to precess around the earth's axis. The angle of inclination of the orbit to the equator, (i) does not change, while the orbital plane rotates slowly around the earth's axis in the opposite direction to the satellite's motion. If this is from West to East, as is usual to take advantage of the earth's angular velocity to reduce the rocket thrust required, the orbital plane rotates from East to West. The appropriate rate of rotation is given by

Rate of rotation $= X = 9.97\ (R/a)^{7/2}$ Cos (i) degrees per day where R and a are as previously defined.

The rotation varies from 0°/day for a polar orbit to 8°/day for a low equatorial orbit.

The second important effect is that the orbital ellipse rotates steadily on its own plane, forward (in the same direction as the satellite motion) for near equatorial orbits and backward for near polar orbits. The perigee thus moves forward (or backward) and the latitude of the perigee is constantly changing. The rate of rotation of the ellipse is given by

Rate of rotation $= 4.98\ (R/a)^{7/2}$ $(5\ \text{Cos}^2\ (i) - 1)$ degrees per day.

The rate varies from 17°/day forward for low equatorial orbits through zero at $i = 63.4°$ to approximately 4°/day backward for low polar orbits. Further information on these perturbations may be obtained from the reference (17).

It is possible to exploit these perturbations to give economy in the number of satellites required as has been suggested recently in connection with the use of highly elliptical orbits (ref. 12). This takes advantage of the long time spent in the vicinity of apogee (where the velocity of the satellite is at a minimum) and by arranging the orbital constants such that the perturbations keep the apogee on the sunlit side of the earth where the traffic is expected to be heaviest, the most effective time utilisation of the satellite is obtained.

APPENDIX VI

RECEIVER AND AERIAL RATING BY EFFECTIVE TEMPERATURE

It is common practice to rate receiver noise performance in terms of the well-known Noise Factor.

This Noise Factor (or Noise Figure) is the ratio by which the input signal/noise ratio is degraded by the receiver and for the better class of receiver a few years ago was typically about 10 db.

In a perfect receiver, the input noise power consists wholly of thermal noise generated in the resistive components of the source impedance. It is not necessary to know the actual value of this resistive component when the concept of Available Noise Power is introduced as the available Noise Power depends only on temperature and bandwidth. In a two-terminal network, Available Noise Power (in Watts) $= kTB$

where k = Boltzmann's Constant $= 1.38 \times 10^{-23}$ joules/°K
T = Temperature in °K $= (°C + 273)$
B = Noise Bandwidth in cycles/sec. (Approximates to "3 db bandwidth".)

From this reasoning, it can be seen that noise factor measurements include temperature as a prime parameter.

For conventional types of receiver, noise factor measurements usually assume a room temperature of 20°C (i.e., 293°K) since most signal sources (signal generators, aerials, etc.) are in thermal equilibrium with an environment of this temperature. The source resistance thus generates an available noise power of 4×10^{-21} Watts/cycle of bandwidth. Thus for a 4 kc/s bandwidth, the power would be 1.6×10^{-17} watts or 168 db below a watt (dbw). The noise power at the input of an imperfect receiver appears to be greater than this by a multiplying factor equal to the noise factor of the receiver.

This method of rating receiver performance may be used to calculate directly the sensitivity of receiving systems in all cases where the ultimate sensitivity of the system is limited by receiver performance. However, in cases where other sources of noise are significant, the Effective Temperature (or Apparent Noise Temperature) is a more convenient parameter which can be applied to the aerial system as well as to the receiver. There are two main reasons behind the use of this idea.

One reason is that in modern receivers using Masers or Parametric Amplifiers the noise contribution from the receiver is extremely low (i.e. the Noise Factor is close to unity). Thus variations in the source temperature are very important since the receiver-generated noise no longer swamps the source noise by a factor of 10 or so as in conventional receivers.

The other reason follows from the advent of Radio Astronomy and Satellite Communications where the signal source is an aerial pointing into space. The volume of space or the objects included in the polar pattern of the aerial may be much lower or higher in temperature than the earth and it is no longer realistic in system design to use room temperature in noise calculations. The net radiation into the aerial from all directions (main beam, side and back lobes) will generate a signal across the aerial terminals and this signal is used in noise calculations.

APPENDIX V

SEPARATIONS REQUIRED BETWEEN TERMINALS TO PREVENT INTERFERENCE BETWEEN SYSTEMS ON THE SAME FREQUENCY

Type of System vs.	*Stationary Satellite Relay*	*Low Altitude Active Relay*	*Passive Relay*
Stationary Satellite Relay	50 miles for co-ordinated systems, up to hemispheric otherwise	150 miles for co-ordinated systems, 2000 miles to hemispheric otherwise	200 miles for co-ordinated systems, 2000 miles to hemispheric otherwise
Low Altitude Active Relay	150 miles for co-ordinated systems, 2000 miles to hemispheric otherwise	150 miles for co-ordinated systems, 2000 miles or more otherwise	250 miles for co-ordinated systems, 2000 miles or more otherwise
Passive Relay	200 miles for co-ordinated systems, 2000 miles to hemispheric otherwise	250 miles for co-ordinated systems, 2000 miles or more otherwise	400 miles for co-ordinated systems, 2000 miles or more otherwise
TH Ground Microwave	100 miles with some co-ordination 250 miles otherwise	250 miles	350 miles
Low Power Ground Microwave	60 miles with some co-ordination, 150 miles otherwise	150 miles	200 miles
Radar	Hemispheric	2000 miles	2000 miles

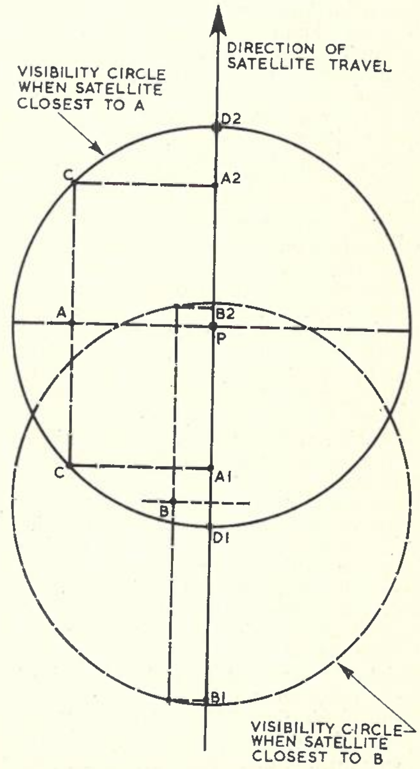

Fig. 16.—Calculation of Visibility Duration.

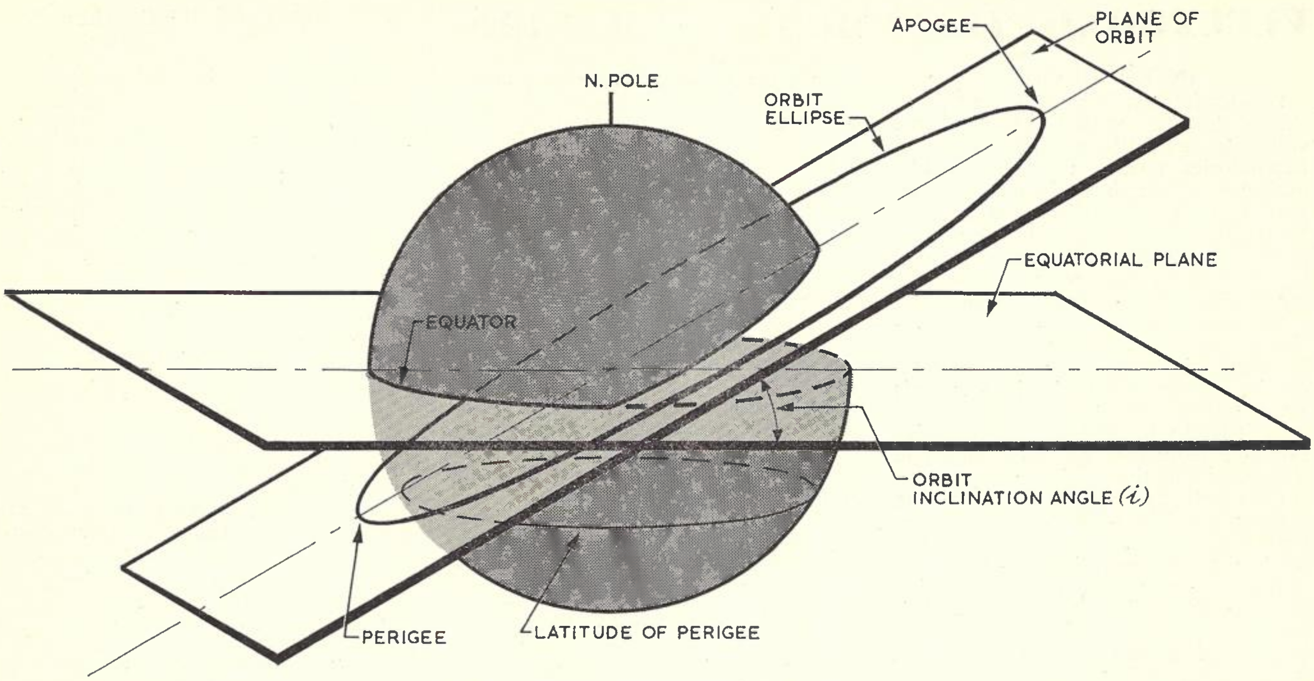

Fig. 17.—Description of Orbit Perturbations.

The measured value of noise power (N) generated by the amplifier, or at the aerial terminals due to radiation pickup, is substituted in the formula $N = kTB$ to obtain a value of T which we call the Noise Temperature. A value of 30°K is readily obtainable at the present stage of development from a Maser Amplifier. This is some 20 db lower in noise level than the typical conventional receiver of 10 db noise factor previously cited (equivalent to an effective temperature of 3,000°K).

The noise temperature of an aerial system depends on the direction in which it is pointing as well as on its polar pattern. The earth itself is a thermal emitter with an effective source temperature of around 150°K so that if the main beam is too low in elevation angle an appreciable fraction of this noise will be picked up. The background level of cosmic noise varies with frequency, being most serious at low frequencies, but even at 1000 Mc/s this accounts for noise from a source of effective temperature up to about 30°K. These sources and any others present may be added and plotted in terms of frequency, time of day and direction, to give the effective noise temperature of the aerial. Details of a method and application to a particular system design are given in reference 18.

APPENDIX VII

TELEVISION BROADCASTING USING SATELLITES

Suggestions have been made that the broadcasting of television programmes from satellites would be advantageous because of the large area which may be served from one transmitter. While such projects are theoretically possible, equipment available or in prospect does not allow practical realisation. Two examples follow.

Using Low Orbit Passive Satellites: A domestic installation much more complicated (and therefore expensive than is at present considered desirable would be required. Calculations then show that transmitters of from 500 KW to 5 Mega-Watt rating with steerable aerials of the order of 100 feet diameter are necessary for the required 5 Mc/s bandwidth.

Transmitters of such power ratings in the U.H.F. band are not yet available and in view of the relatively low efficiencies and small physical size associated with such frequencies it is by no means certain that such high powers are possible in one unit. Thus the parallel connection of a multiplicity of smaller units with attendant phasing problems may be necessary to obtain the required power. New problems such as radiation hazard would also need to be considered as the equivalent radiated power would be up to 50 million KW from a steerable aerial. (The recommended safety level of exposure is set at a maximum radiation level of 100 milli-watts/sq. cm.)

Using Active Satellites: In this case one can assume a domestic installation similar to those in common use today. It would probably be feasible to mass produce U.H.F. receivers at an economic price requiring a signal of around —1000 dbw for satisfactory performance. A path attenuation of 170 db would be a typical figure, so assuming a satellite with aerial beams just covering the service area (implying a gain in the range 20 to 10 db), the transmitter powers required would range from 10 to 100 KW. Such powers are not yet in sight for satellite-borne equipment, though future developments in rockets and nuclear or other power supplies may make such a scheme practicable.

ELECTRONIC TELEPHONE EXCHANGES

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INTRODUCTION

Greater interest is being progressively shown in the subject of electronic switching, particularly since the Bell Laboratories opened their first public exchange at Morris in Illinois late last year (1). In this article some of the basic principles used in electronic telephone exchanges will be discussed together with some comments on the types of components used in them.

The first and most fundamental question to be examined is: what advantages may be obtained from the introduction of electronic switching? At this stage, this question cannot be answered quantitatively, but it is certain that considerable reductions will be obtained in power consumption, weight and volume. An estimate has been formed that, in general, a weight and volume of 20% of that of a corresponding electro-mechanical exchange may be expected (3). The power consumption reduction is rather more difficult to predict, as it will depend to a certain degree on the type of components used, in particular, on the usage of gas tubes or transistors as the predominant logic element. A further complication exists in that the power consumption in an electro-mechanical exchange varies directly as the load carried whereas it varies little with load change in an electronic system. However, a power consumption of the order of 10% of that of a corresponding electro-mechanical exchange can be reasonably expected. Apart from this, there is a much wider scope for providing new and additional facilities due to the considerably greater flexibility and higher operating speeds of electronic equipment. To offset this, however, there are several minor problems (4), which will have to be examined carefully before the introduction of electronic switching, the more important of which are line protection, line testing, and lack of reversal on subscribers' lines; these, however, are not likely to prove insurmountable obstacles.

BASIC REQUIREMENTS OF AN ELECTRONIC EXCHANGE

There are three main functions which must be carried out by a telephone exchange; these are:—

(a) switching of the speech path;
(b) storage of information concerning calls which are in progress;
(c) control of the switching and storage circuits.

There are various methods of achieving each of these functions which differ widely in principle for various types of system. In the step-by-step system, all three are combined in every switch. Each swtich contains sufficient control circuitry (relays) to enable that switch to be set up to form part of the switched path; the switch also contains the contacts which actually carry the switched path; the information storage regarding the state of the call consists of signals fed into the switch via the subscriber's loop or the private wire. Other information concerning the route of the call is contained in the spatial location of the wipers.

In a common control system, the control circuits for setting up the switches is dissociated from the switches themselves and is concentrated in a block of equipment known as common control equipment (C.C.E.). This enables economies of equipment to be achieved, as the control circuits can be used more efficiently. The switched path is routed, for example, through crossbar switches via contacts which are operated in a suitable manner to connect the appropriate subscribers together. Information is stored in the crossbar switch concerning both the route of the call and also the state of the call.

In the electronic system, all control functions are usually carried out by C.C.E. and the path is routed via electronic switches. Some types of switch are continually controlled by a memory while others are said to "possess memory", i.e., they can be turned on and will remain so until turned off, somewhat like a relay which is used to lock itself on.

In the electronic switching system, each of the three primary functions, switching, information storage and control, can be quite readily segregated, which enables the design of the circuitry for each purpose to be optimised, and also enables much greater flexibility to be achieved. Also, as each section has only the one basic function to perform, higher operating efficiencies can be achieved through the use of sharing.

SPEECH PATH SWITCHING

There are three broad methods by which speech paths can be set up between subscribers, using what is termed

(a) space division switching (S.D.)
(b) time division switching (T.D.)
(c) frequency division switching (F.D.).

Space Division Switching. Space division systems are those in which an actual physical continuous path is set up between two subscribers via a switching network. All electro-mechanical switching systems fall into this category. The switching network consists essentially of an array of cross points, some of which are operated in order to set up a particular call. This is illustrated in Fig. 1 for a very simple link trunked S.D. system. Considering a call from Subscriber 2 to Subscriber 3 using link 1, the crosspoint common to Subscriber 2 and link 1 would be operated, likewise that common to link 1 and Subscriber 3 to complete the call.

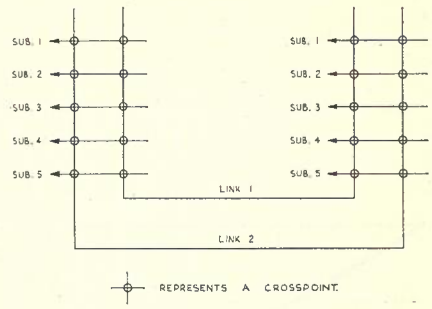

Fig. 1.—Basic Link-Trunked S.D. System.

This type of system is relatively expensive in that many crosspoints are required, and the number required grows much faster than the number of subscribers catered for. However, this can be largely offset by using components for the crosspoints which can both act as a switch and also maintain themselves in either the on or off condition without the need for any other circuitry, i.e., components which are said to possess memory. One such component is the gas tube. It will remain in either the "on", or low resistance state once it has been ignited until it is extinguished, provided that the power supply is not interrupted. When extinguished, it presents a high resistance across its terminals. These high or low resistance conditions, together with its ability to maintain itself in either condition until switched to the other, have resulted in much developmental work being spent on systems using gas tubes, an example of which is the Morris exchange in U.S.A.

The operating characteristic of a typical gas tube is shown in Fig. 2. The tube is normally supplied from a voltage source V_s via a limiting resistance R. A load line is shown for these quantities, which intersects the gas tube characteristic at three points, A, B and C. A and C are stable operating points corresponding to the on and off conditions respectively. The dynamic (or switch) resistance is given by the slope of the gas tube characteristics at these points. The tube will be triggered to the on condition if the supply voltage is momentarily raised above the breakdown voltage V_B (usually by a pulse) or the off condition if the supply voltage is momentarily lowered below the extinc-

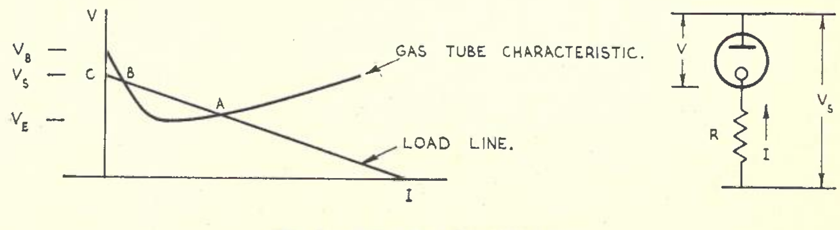

Fig. 2.—Gas Tube Characteristic.

* See page 79.

tion voltage V_E (again usually by a pulse).

The resistance of the gas tube switch is of interest because it determines the loss through the switching system. A gas tube has been developed in the Bell Laboratories which can be operated to utilise a negative ressitance region of its characteristic to enable losses due to transformers, etc., to be reduced (5).

Two examples of exchanges using gas tubes are the Bell Labs. exchange at Morris in U.S.A., which initially is equipped for 600 lines, and a 240 line exchange built by the L.C.T. in France (6). In each of these systems the subscribers are "trunked" via a concentration stage to the main switching stage and then to the called subscriber via the concentration stage once again, as shown in Fig. 3. The purpose of the concentration stages is to increase the traffic load in the main switching stage, thus enabling it to be operated at a higher efficiency. This is necessary in any space switched system, because the number of crosspoints tends to be roughly proportional to the square of the number of inlets or outlets connected to the switching network. It is desirable to minimise the number of crosspoints from the control aspects as well as from economic considerations as this would simplify various access problems.

An outline of the switching and bias paths of the French system is shown in Fig. 4 but control functions are omitted. Three gas tube crosspoints are shown connecting a path from subscriber 45 to subscriber 88. The 240 subscribers are connected in six groups of 40, with ten junctions from each group, providing 60 junctions to the main switching stage. Each concentration stage is a rectangular array of 40 x 10 crosspoints, similar in form to Fig. 1. The use of the transformer to supply a maintaining potential to the gas tubes should be noted. The 60 junctions are connected to both vertical and horizontal rows in the main switching network, and a path can be completed between two junctions by ignition of the one gas tube common to both junctions. The junction transformers supply —115 volts to the columns and earth to the rows, consequently a supply-maintaining path can always be provided. This type of system is not particularly well suited to handling very large networks.

The Morris exchange operates on a slightly different principle, in which the two ends of the path through the main switching network are marked, and a chain of 6 gas tubes is ignited to form a path through the main switching network, as shown in Fig. 5. The junctor is a part of the control equipment and supplies the maintaining potential.

PNPN diodes are semi-conductor elements with a similar type of characteristic to that of a gas tube, but they operate at a much lower voltage, thus consuming less power. They also switch faster, but at present are more expensive than gas tubes. The circuit applications are generally similar to those of gas tubes. A typical characteristic is shown in Fig. 6. The breakdown voltage V_B may be in the range 20-200 volts, while

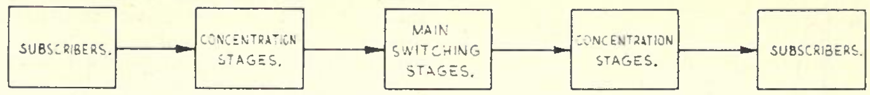

Fig. 3.—Basic Electronic Exchange Switching Plan.

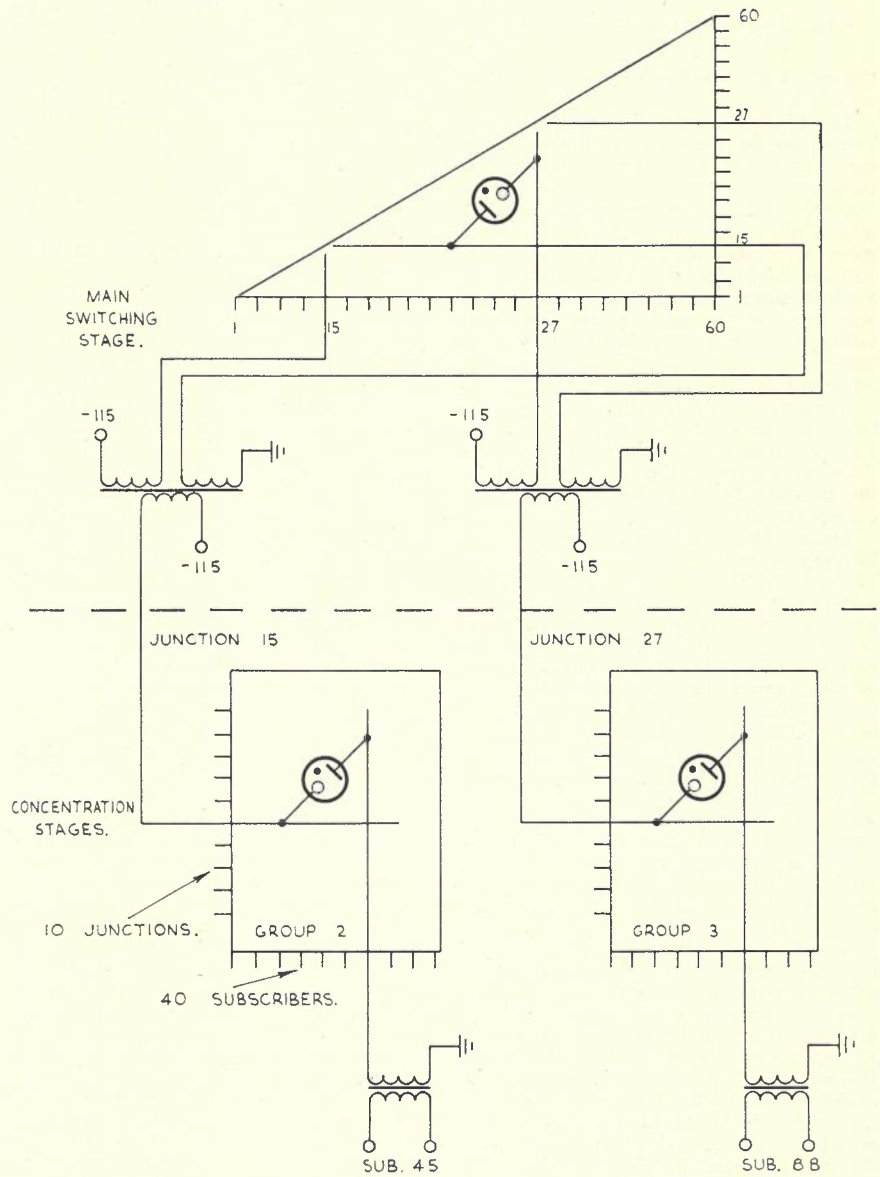

Fig. 4.—Switching Layout of L.C.T. 240-Line System.

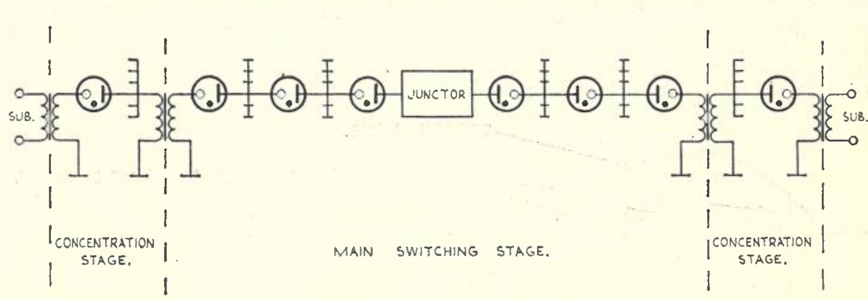

Fig. 5.—Switching Layout of Morris Exchange.

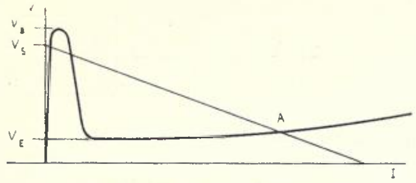

Fig. 6.—PNPN Diode Characteristic.

the extinction voltage V_E is of the order of 1 volt.

The Philips organisation in Holland is known to be working on the development of an S.D. system using PNPN diodes (7).

Silicon diodes can be used as cross points; they form possibly the cheapest form of crosspoint, but have the disadvantage that they require a continually applied signal to maintain them in an "on" or "off" condition, thus necessitating the use of an additional element possessing memory, which reduces the advantage of the low cost of the diode.

An experimental 20 line exchange has been constructed by the L.C.T. in France using silicon diodes, with ferro-resonant magnetic flip flops to provide the memory function for each operated crosspoint (8).

Time Division Switching. Time Division switching involves the sharing of part or all of the connection path between all subscribers. In order to achieve this, pulse amplitude modulation is generally used and the various channels are time multiplexed. The principle of pulse amplitude modulation (P.A.M.) is illustrated in Fig. 7. A speech wave is sampled at regular intervals and a pulse is transmitted with amplitude proportional to that of a speech wave at the instant of sampling. The speech wave can be recovered by passing the pulse train through a low pass filter. Sampling theory requires that the sampling frequency should be at least twice the highest frequency which is to be transmitted through the system. This places a lower limit of approximately 8 kc/sec. on the sampling frequency for a speech switching system.

If the speech wave is sampled at 8 kc/sec. then a pulse is transmitted each 125 microseconds, as shown in Fig. 8. If each pulse were 2.5 microseconds in duration, then the conductor carrying this pulse train could carry 49 other additional pulse trains interlaced with the one considered. This would enable 49 additional channels to be provided over the one conductor as shown in Fig. 8. A simple time shared system using this principle is illustrated in Fig. 9. Each subscriber is connected to the input of a pulse amplitude modulator (P.A.M.) and to the output of a filter. Each P.A.M. generates a pulse at a different time in the basic recurring intervals of 125 seconds, or frames, shown in Fig. 8, i.e., in different time slots, as they are called. Thus the output of each subscriber will have a particular time slot on the common conductor. A one-way connection can be provided from Sub. 2 to Sub. 3 by closing switch S_3 once each frame during the time slot containing the output of the P.A.M. used by Sub. 2. Thus, only the output of this P.A.M. will be connected to the input of the Sub. 3 filter, thus providing a through connection. Other calls could be set up similarly by operating the appropriate switch in the appropriate time slot, providing, in effect, simultaneous transmission of several channels through the common conductor.

This type of exchange is more economical on switching points, as the number required is directly proportional to the number of subscribers catered for, hence in large systems, considerable economies may be realised. This type of exchange is very dependent on the use of dynamic memory for storage of time slot/switch information.

Various systems have been developed which use time shared paths. All of those developed so far use a mixture of time division switching in large concentration groups with space division switching between the concentrator groups. Examples of these types of exchanges are the British Highgate Wood exchange and the American Stromberg Carlson system.

The Highgate Wood exchange was developed by the B.P.O. and the five British telephone manufacturers as a joint enterprise. It consists of a number of 800-line groups which are interconnected on an S.D. basis, but time sharing is used within the groups (9). The basic subscriber's circuit is shown in Fig. 10. Sampling is carried out at a 10 kc. rate, giving a frame of 100 microseconds. 100 time slots are provided giving 100 outlets per group of 800. Amplification is used on the filter, or receive, side to compensate for the energy loss due to the sampling process and hybrid. As can be seen, this exchange operates on a 4-wire basis, which is necessary in any system having dissimilar sending and receiving circuits.

The Stromberg Carlson Exchange was constructed for the U.S. Army. It is a 280-line system using time sharing within groups of 20 subscribers, and space division switching between groups (10). In this exchange, the speech signal does not remain in the form of a P.A.M. signal throughout the switching stages as it does in the Highgate Wood exchange, but is demodulated back to audio in the main switching stages. P.A.M. is only used on the concentration stages. This system is also a 4-wire system with amplification provided in the receive path. An outline is shown in Fig. 11.

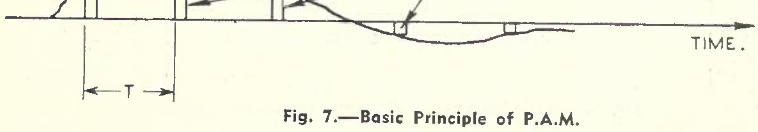

Fig. 7.—Basic Principle of P.A.M.

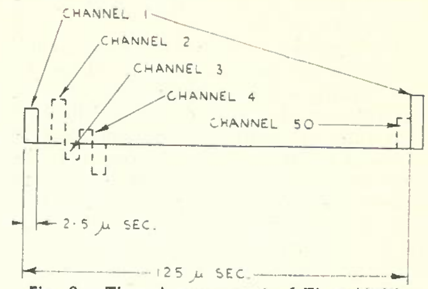

Fig. 8.—Time Arrangement of Time Multiplexed P.A.M. Channels.

A further system is the S.C.A.T.S. (Space Controlled And Time Shared) Mark I system under development in the A.P.O. Research Laboratories. In this system time sharing will be used throughout all stages rather than a mixture of time and space switching as in the two previously described systems. It is a two-wire system without amplification as distinct from the other two 4-wire amplified systems. Details of this system will be given in a future paper if development continues.

Frequency Division Switching. The third manner of switching, frequency division switching, uses principles somewhat similar to those used in carrier telephone and telegraph systems. It has not found any practical application so far, and is mentioned only for the sake of completeness.

INFORMATION STORAGE

There are two basic forms of information storage, or memory, used in electronic telephone exchanges. One relates to the function of a particular exchange as a part of a network and must contain such data as trunk charging rates, alternative routing data, etc. This is a semi-permanent memory, or static memory, which is only rarely changed. Information of this nature can be stored on a magnetic drum (e.g., Lee Green Exchange, U.K.), flying spot memory tubes (Morris Exchange, U.S.A.) and other similar types of device.

The other form of memory relates to the moment by moment state of the exchange as an entity within itself and contains data to maintain the existing connections between subscribers, data concerning the condition of subscriber lines (free, busy, etc.), connecting links, etc. This dynamic memory contains information which changes quite rapidly, and some form of readily variable memory is required, such as a magnetic drum (Lee Green), barrier grid tube store (Morris), magneto-strictive line (Highgate Wood), binary counters (Stromberg Carlson), magnetic cores, gas tubes (S.C.A.T.S. Mk. I), etc.

As the static memory information content does not change, some form of "semi-permanent" storage must be used which is not liable to cause information mutilation with variation of power supplies (including momentary interruption), passage of time, etc. This restricts the choice to permanently wired diode networks (which are very expensive and not used), magnetic drums or the flying spot store.

In the magnetic drum, information is "written" on to a drum having a magnetic surface in much the same way as signals are recorded on magnetic tape. There are usually many tracks, each with its own reading and writing heads. These drums are usually precision-engineered devices operating with a tolerance of the order of one-tenth of a mil. (0.0001") and at speeds up to 6000 r.p.m. Elaborate circuitry is usually required to maintain a precise drum speed to keep it rotationally synchronised with the remainder of the system, especially in time-shared systems.

The flying spot memory tube is essentially a cathode ray tube with a photographic plate acting as a mask across its end. Light from the spot on the face of the tube is detected by photo-electric cells, depending on whether the photographic plate is transparent or opaque at a certain point. The information is "stored" on the photographic plate by means of the transparency or opacity at various points. In the Morris Exchange the capacity of the memory is over 35,000 bits. This type of storage is wholly electronic and is suitable only when large quantities of information must be stored.

In dynamic memories, permanence of information storage with power supply drop-outs is not so vital, consequently the more commonly used memories including magnetic cores, magnetostrictive delay lines and the barrier grid tube are used.

Magnetic cores are usually made of ferrite material with a square hysteresis loop, i.e., they will retain their magnetism if magnetised by a current greater than some specific value depending on the core. Information can be written into the cores by magnetising the cores in one of the two directions. Information can be "read" by measuring the voltage induced in reading wires when the cores are pulsed. The cores are very small toroids of the order of 2 or 3 millimetres in outer diameter with a hole about 1 millimetre in diameter.

Magnetostrictive delay lines consist of a length of magnetostrictive wire with reading and writing coils at each end as shown in Fig. 12. A pulse representing a bit of information is applied to the writing coil, which produces a mechanical shock, or stress, in the wire. This travels at the velocity of sound down the wire to the other end, where it induces a voltage in the read winding through the magnetostriction phenomenon. If this pulse is amplified and reapplied to the write winding, it will circulate through the delay line indefinitely, i.e., it will be stored. Usually many such pulses are stored in the one delay line. Control circuitry is necessary to either store a pulse in a vacant time slot or to remove it. This is not a "random access" memory, i.e., immediate access to a given bit of information is not always available, as the pulses can only be read at the instant of their arrival along the line at the read winding. Up to about 100 bits could be conveniently stored in such a delay line.

The barrier grid tube is basically a cathode ray tube with a target plate of dielectric material in place of the usual screen. Spots on the dielectric represent tiny capacitors, which are charged by the electrons comprising the beam current. The information is stored by allowing the beam to charge a given spot, and information is read by observing the amount of current required to discharge this spot. This type of memory is inherently suited to applications where a lot of information (e.g., 50,000 bits) is to be stored.

CONTROL FUNCTIONS

Control circuitry is required for all aspects concerned with the setting up and releasing of paths between subscribers. As these functions usually occupy only a short time, it appears logical to share the control equipment among groups containing appropriately selected numbers of subscribers, and this is what in fact is almost standard practice in some form or other.

The precise nature and function of common control equipment (C.C.E.) depends of course on the basic form of the system concerned, but two features are common to all systems:

1. Common control equipment operates on a "scanning" basis, locating subscribers which need attention. Each subscriber's line circuit is examined in turn and various functions are carried out depending on the state of the line

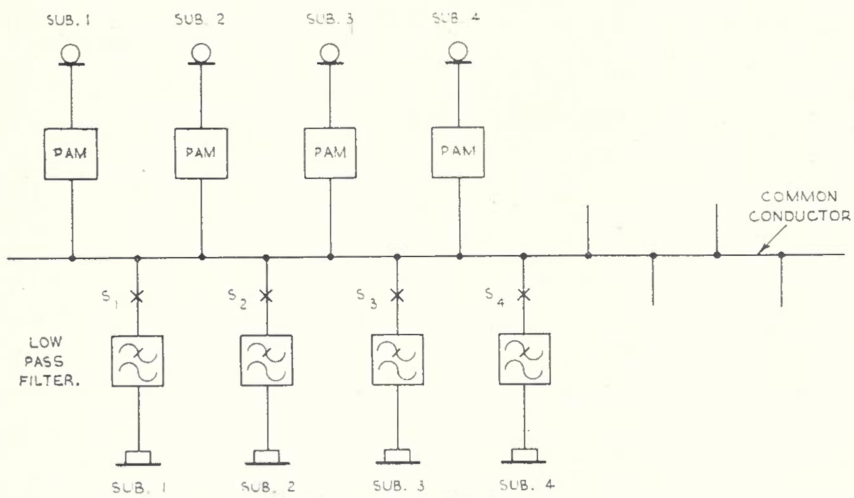

Fig. 9.—Basic T.D. System.

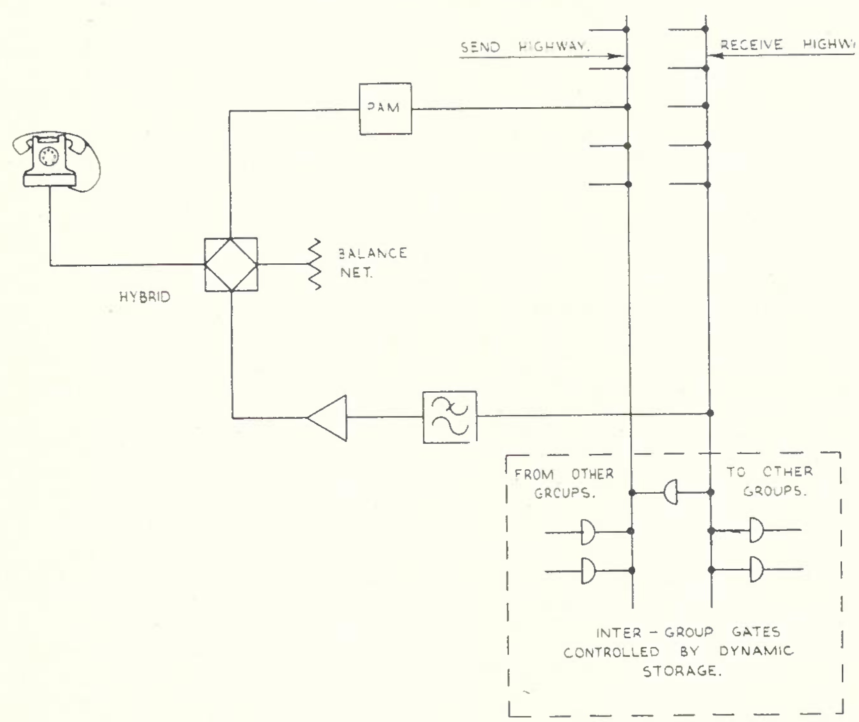

Fig. 10.—Switching Layout of Highgate Wood System.

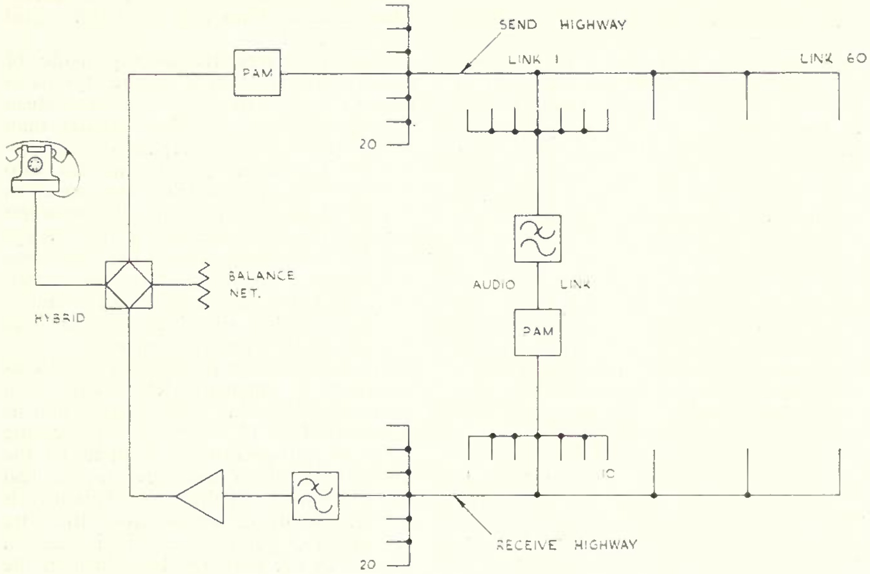

Fig. 11.—Switching Layout of Stromberg Carlson System.

circuit, information stored in the memory and the state of the C.C.E. In some systems, true "one at a time" operation is used, in which control circuits are associated solely with the subscribers being served until the necessary action is completed. In these systems, access to the relevant section of the C.C.E. by other subscribers is barred until the function being carried out is completed. As an example of this, consider the sequence of events after a subscriber lifts the handset. Some form of marking signal will appear in the line circuit, which will be recognised when the line circuit is next scanned. The C.C.E. would then lock on to this line circuit and then carry out various actions, which could be to cause dial tone to be connected to the subscriber concerned, and a register to be connected to receive dialled impulses. The control circuitry concerned would then be freed to continue scanning line circuits until a further subscriber requires attention.

In other systems, several circuits may have simultaneous shared access via time slots, with necessary actions being carried out within the time duration of a time slot. This enables the control circuits to handle a greater number of subscribers, but the control circuits are necessarily more complex and must work at higher speed. This is known as time-shared control.

2. One function normally carried out by the control circuitry is the selection of the called subscriber, followed by application of the appropriate signalling tones, etc. The information necessary to make this selection must be dialled by the calling subscriber; as this could take a long time (in comparison with the operating time of the control circuitry), several registers are usually provided for the reception of this information, and are associated with a calling subscriber when required. This enables the main control circuitry to be freed during the dialling period. Usually a forced throw out is provided to prevent registers being held by faulty lines or subscribers who fail to complete dialling within a reasonable period. After the register has received all necessary information, the C.C.E. would carry out the subsequent actions to complete the setting up of the call.

The operation of control equipment cannot be considered in more detail, because it depends very heavily on —

(a) the type of speech path (i.e., S.D. or T.D.) and the components used in it;
(b) the type of memories being used;
(c) whether "one at a time" or "time shared" control circuitry is employed.

CONCLUSION

As may be seen from the preceding, there are many ways in which systems may be organised, using either SD or TD switching, or a mixture of the two, also there are many types of components which can be used to carry out the various functions, thus there is a great variety of possible types of electronic exchange, and it will be necessary to test various attractive possibilities in order to evaluate them from the economic, maintenance and reliability viewpoints. To do this, it is inevitable that many field trials such as that at Morris in U.S.A. must be held before the best system is obtained. These trials will give considerable information concerning these exchanges, but there necessarily must be a variety of types tested, and it is to be hoped that results will be made freely available between administrations.

In this article, a brief survey of principles of operation and some of the less familiar components have been described. (The author assumes that the transistor has now become a familiar component!)

Some existing systems will be described in future articles, also the A.P.O. Research Laboratories system if development is continued.

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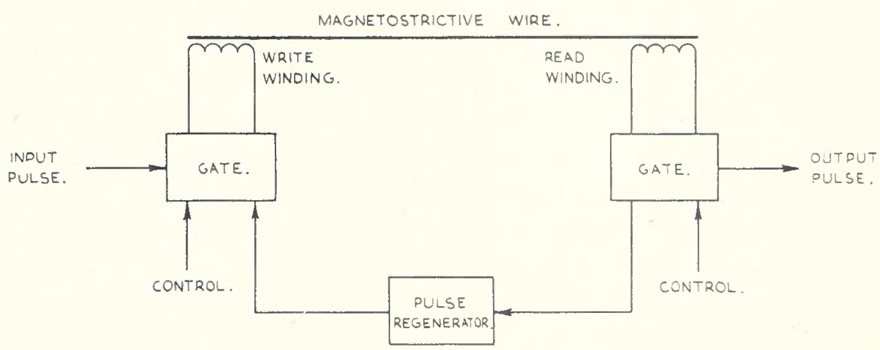

Fig. 12.—Basic Arrangement of Magnetostrictive Delay Line Memory.

IMPRESSIONS OF AN OVERSEAS VISIT BY A LINES ENGINEER

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FOREWORD

This article consists of a number of impressions of a technical and general nature gained on a visit to Europe and North America in late 1959. The visit was made primarily to deal with a number of technical matters in connection with the contract for the Sydney-Melbourne coaxial cable awarded to Felten & Guilleaume Carlswerk A/G, Cologne, (F & G), but the opportunity was taken to investigate various aspects of external plant practices, particularly cable design and application. This article deals with general topics only, and a second one dealing specifically with cable design and application will appear in a subsequent issue of the Journal.

INFLUENCE OF NON-TECHNICAL FACTORS ON TECHNICAL PRACTICES

General

Probably the most interesting and most important observation to be made from an overseas visit is the important influence which non-technical factors can have on technical designs and practices. While it is fairly obvious, looking from Australia, that differing geographical conditions and other factors must have an influence on designs and practices, nevertheless, first-hand observation overseas is necessary to appreciate how important these factors are. In fact, it is a reasonable first assumption that, whenever some overseas practice does not seem soundly or logically based in the view of Australian knowledge and experience, non-technical factors are the reason. Considerable caution must therefore be exercised in adopting overseas practices, particularly if it means departure from accepted and apparently satisfactory Australian practices.

Some of these factors are discussed in the following paragraphs. The list is not exhaustive and many chance and transitory factors influence technical decisions. As an example of the latter an enquiry was made why lead sheathed and not Stalpeth sheathed coaxial cable was to be used for the large trunk installation programme now commencing in the U.S.A. An explanation given was that the Western Electric Company's coaxial cable works had lead sheathing facilities only.

A word on the organisation of the telephone services overseas may be of interest. In the U.S.A. the telephone system is privately owned; about two-thirds of the facilities belong to the Bell System; the remainder to a large number of companies called the Independents. The Bell System has over 60 million subscribers and it is by far the largest telephone organisation in the world. It consists of four separate sections; the Bell Telephone Laboratories, the Western Electric Co., the American Telephone and Telegraph Co. (the A.T. & T.) and nineteen Bell operating companies. The operating companies provide telephone services in the different geographic areas of the U.S.A. and in Quebec and Ontario Canada. The A.T. & T. corresponds to Central Office in Australia, and is the central co-ordinating and policy-making body. It also provides the long distance trunk line services. The Western Electric Co. is the manufacturing and supply organisation. It is the largest telephone apparatus and the largest cable manufacturer in the world. The Laboratories, as well as engaging in the scientific and technical research which has made them world famous, prepare the manufacturing specifications and technical standards for the whole System in association with Western Electric and the A.T. & T.

The scene in England and Germany is much more familiar. Telephone services are provided respectively by the British Post Office (B.P.O.) and the Deutsche Bundespost (Bundespost). These are Central Government Departments and provide a similar wide range of postal and telecommunication services as we are accustomed to in Australia. Unlike the Bell System, neither of these organisations are extensive designers and manufacturers of telephone plant and apparatus, but buy most of their requirements from private manufacturers. Both England and Germany are large exporters of telephone equipment and engineering services, but the Post Office in each country is the major customer for the home industry.

Price Levels

Relative wage and price levels are a most important factor. As an example, this factor has an important bearing on the way construction and production jobs are done. The question here is the proportion of manual labour to machine time. In U.S.A., with a very high wage rate, as much labour as possible must be eliminated from every operation. On the other hand, the need is less pressing in the United Kingdom and Germany. And, in fact, it is evident to a visitor to those countries that every endeavour is made to substitute machines for men in the U.S.A., whereas in England and Germany manpower tends to be regarded as the basic commodity. Australia, by comparison, appears a well mechanised country, more so than the relative wage rates would indicate; possibly this is because the acute shortage of labour in Australia over the past 15 years has forced the pace of mechanisation beyond the economic level. There is also, perhaps, some uncritical acceptance of American methods in Australian industry generally without fully appreciating their economic limitations outside of the American economic environment.

An obvious operation for comparing the degree of mechanisation in countries is material handling. It is very striking to see numbers of men manually handling material, loading trucks and so on in English and German cable factories, whereas in U.S.A. work is extensively mechanised and little labour is employed. Australia appears to be well mechanised. To give an example of the care that must be taken, however, in assessing the degree of mechanisation justified and the risks involved in accepting overseas standards, the following example in regard to warehouse operation compares the use of manpower with the use of a fork-lift truck:

	Australia	U.S.A.
Price of fork-lift truck	£2,500	£1,000
Weekly wage of warehouseman	£15	£40

Obviously the Australian factory for best economy would employ more warehousemen and fewer fork-lift trucks than a comparable factory in the U.S.A., provided, of course, that the labour was available.

In each country visited, an enquiry was made about wage levels, taking as the criterion the wage paid to an operator in the cable industry (i.e. a non-skilled man with a certain amount of knowledge acquired on the job and paid a margin above unskilled work.) Typical figures were as follows:—

U.S.A. (New York area) £A45 per week plus; 40-hour week.
Canada £A32; 40-hour week.
Australia £15; 40-hour week.
U.K. £A12; 44-hour week (now 42-hours).
Germany £A11; 44-hour week (now 42 hours).

These figures are not exact because of the influence of overtime and bonus payments which vary from factory to factory in the same country. Also in England and Germany heavy social service payments are made by the factories on a per capita basis. Nevertheless, the figures are satisfactory for comparative purposes and show, contrary to the general opinion in Australia, that our wage levels are not high by overseas standards.

These wage levels, however, are no indication of relative price levels for raw materials or manufactured goods; for instance copper, the basic raw material of the telephone industry, has a world standard price. Plastics are cheaper in the U.S.A. than in Europe and U.K. and, as a general rule, are more expensive in Australia than elsewhere. Manufactured goods tend to be dearer in Australia than in other countries. While it proved impossible to find any item of plant or material to draw a price comparison similar to the wages comparison some trends are:—

1. The only price levels which seem clearly lower in Australia than overseas are some items of foodstuffs.

* See page 79.

2. Volume produced manufactured goods seen on retail sale such as domestic electrical apparatus and household utensils are, as a rule, more expensive in Australia. As a general rule, price and quality are best in the U.S.A.
3. Mechanised tools, construction plant and similar are low in price in the U.S.A.
4. The tax free retail prices of the Volkswagen is £450 in Germany, the Chevrolet £1,000 in U.S.A. (basic model) and the Holden £885 in Australia.

Regarding telephone material, cable and indoor apparatus made in U.K. and Europe is cheaper than when made in Australia. The position in regard to U.S.A. manufacture is less certain. Catalogue prices available are for supply to the Independent Telephone industry and most items are very highly priced by Australian standards, except cable which is a little dearer than in Australia. However, the Independent companies are small buyers and the prices listed are probably not representative of those paid by the Bell Companies. These should be low as manufacture by the Western Electric Co. is on an enormous scale, items are highly standardised and specifications are only changed if proved uneconomical on a balance of manufacturing, installation and maintenance costs; from the makers point of view, specifications are not subject to the whims of the customer. As an example, at the Kearny cable works of the Western Electric Company in October, 1959, 670 workers were employed and output was at the rate of 4,300,000 pair miles of cable per year. The output of Austral Standard Cables Pty. Ltd., with a comparable staff is some 500,000 pair miles per year and their productive operations compare very favourably with any cable plant seen in England and Germany. The result was achieved by a degree of mechanisation only made possible by the enormous demands for cable, and the positive planning made possible when the one organisation is both maker and user of the material.

While conclusions must be drawn with caution, Australia appears to be a country where manhours are comparatively cheap and manufactured goods and plant items are expensive. The lesson to be drawn, of course, is that a particular technique may be economically best in one country because of its labour/material costs ratio, but quite uneconomic in a country with a different relation between the costs of manhours, machines and materials.

Geographical and Economic Factors

These have an obvious bearing on telecommunication practices. For instance, subscribers distribution methods used in Australian and American cities where most people live in suburban houses will be quite different to those in German cities where people live in large apartment buildings. Again, if the terrain is rocky and mountainous, broadband radio is likely to be preferred to trunk cables. Economic factors will determine, for instance, the proportion of residential and business telephone services; the proportion of local trunk traffic and the volume and direction of trunk telephone services. These factors were observed fairly closely in Germany and England, and to a lesser extent in Holland and in North America.

The United Kingdom and West Germany are both similar in size to Victoria (U.K. 93,000, West Germany 95,000 and Victoria 88,000 sq. miles) but the populations are U.K. 50 million, West Germany 55 million and Victoria 2.5 million. Holland has 11 million people and is 13,500 sq. miles in area. The terrain in each country is largely flat and there are few apparent natural obstacles to transport and communication.

In contrast to these small, densely populated countries, the U.S.A. and Canada resemble Australia in their size and spaciousness. As a result trade and commerce carried out on an international basis between European countries corresponds geographically to interstate or even intrastate trade and commerce in Australia and North America. There is much greater freedom of intercourse and consequently a much greater volume. Hence the pattern of trunk telephone traffic is quite different. Long distance traffic such as Sydney-Melbourne, New York-Chicago, is vitally important in their countries, whereas short distance trunk traffic within the nations border is more important, both administratively and in volume in the compact European nations than the long haul international circuits.

London is the social, economic and administrative centre of the U.K. It is also one of the largest cities in the world. In consequence it is the focal point for trunk telephone traffic and the B.P.O. trunk network is laid out in star formation with London at the centre. Large blocks of circuits are required to connect London with cities such as Birmingham, Manchester and Sheffield and to provide for centres beyond. Traffic is densest at the London end and tapers with distance from London. The consequent heavy demands for trunk circuits were probably the reason why the B.P.O. pioneered the use of coaxial cable and is the largest user in the world on an area basis. London itself is the centre of an enormous urban area with a large residential and industrial telephone service and all the problems encountered in Melbourne and Sydney could be expected to exist in a worse form in London.

A feature of West Germany is the comparatively large number of medium-sized cities and the absence of one single large city comparable to London or Paris. Berlin, of course, is a large city, but it is effectively outside the normal range of telephone communication in the country. Hamburg has 1.7 million people, Munich 1.1 million, and there are six other cities over half a million. There are many cities of the population of Newcastle, Wollongong and Geelong. The cities are very compact and cover a small area. Most people live in several storey apartment buildings and there are few private houses. There is "no suburban sprawl" as we know it and there is a clear demarcation between urban and rural areas. As an example, travelling by train from Cologne (population 670,000) to Dortmund (580,000), the train passes through Leverkusen (72,500), Dusseldorf (595,000), Mulheim (151,000), Essen (661,000) and Bochum (325,000). The distance overall is about 60 miles—less than the rail distance from Dandenong to Geelong. This is one of the most heavily industrialised areas in the world, yet it is most surprising to an Australian that more than half the distance is through farming country devoid of any sign of industry or urbanisation.

Because of the compact self-contained cities the problem of providing subscribers services is comparatively simple. There are few transmission difficulties with local calls and there are few problems of the type experienced in Australia with residents on the outskirts of the city.

The proportion of residential telephone services is relatively low and the proportion of business services high. Hence there is a heavy demand for trunk line service, particularly short distance services, say 20 to 40 miles; there is proportionally less longer distance traffic. Technical development has, accordingly placed emphasis on meeting demands for heavy blocks of circuits over distances of 20 to 50 miles rather than over longer distances. For instance, Cologne has heavy traffic to the cities in the Ruhr mentioned above, but has lighter demands for trunk traffic to such cities as Frankfurt 100 miles away and Munich 200 miles away. As there is no focal city in West Germany the trunk network is not laid out in star formation but in a figure 8 with Frankfurt at the middle, Hamburg at the top and Munich at the bottom. The traffic density would not be comparable at any point with that in the vicinity of London and broadband facilities were not required until at a much later stage than in England.

Holland is similar to Germany although there is a greater degree of centralisation with the large cities of Amsterdam and Rotterdam. Distances between cities are small and their trunk problems look more like a junction problem to Australian eyes.

Cities in North America are similar in general layout and appearance to Australian cities of the same size and type. For instance, seen from an aircraft the suburban development of New York, Denver, St. Paul, and Salt Lake City resemble similar suburban development in Sydney, Melbourne, Adelaide or Brisbane; and, in fact, the telephone problem is much the same. Touring new housing estates in Toronto, Chicago and San Francisco, the comparison with residential areas in Sydney and Melbourne was striking. The cities consist of what is called the "down town" section which corresponds to the business section of the city proper, as known in Australia. An interesting feature here, is that in spite of the presence of a number of large multi-story buildings, the average area density of office workers in the "down town" section is probably comparable with that in Sydney and Melbourne, because the sky-scrapers are usually few in number compared to the total number of buildings in the area. Outside the "down town" section there is, just as in Australia, an industrial area and an inner rather poor type of residential area where the houses are either of the apartment type or small houses close together; then further out, large areas of residential suburbs interposed with new industrial areas. This is the "suburban sprawl" just as in Australia except that the residential building blocks seem smaller than here. The comparison must not be taken too far of course; the U.S.A. has 18 times the population in the same area and consequently the urban territories in the East and in California are much greater in area and population than any in Australia.

It is apparent that the urban telephone problems have many points of similarity in each country. One difference however, is the higher telephone density in the U.S.A. with the result the residential telephone services penetrate into a lower income earner group than in Australia. Hence there is a heavy demand for telephone services in the tenement residential sectors where the population density is high and the telephone density per unit area is correspondingly high.

Climatic Conditions

This is an obvious point of difference between different countries, but its effects may be more far-reaching than would be expected. Two examples are quoted for the U.S.A.

The Isoceraunic Level: This is the average number of days per year on which thunder is heard and is the accepted measure of the intensity of lightning in an area. Obviously more elaborate and more expensive protection of external plant is required where the isoceraunic level is high. There is a great difference between the isoceraunic level in Australia and U.S.A. Nearly all of Australia is under the 30 days per year limit which is exceeded only in the mountainous areas of the Eastern States and in parts of the tropical north; nearly all of the U.S.A. is over the same limit, including most of the heavily populated part of the country. Much greater care must obviously be paid in the U.S.A. to lightning protection.

The Harsh Winter in North America: In all except the Pacific coast area and the south-east of the U.S.A. outdoor construction work ceases during the cold months. This necessarily adds heavily to costs as construction plant and organisations are idle for a considerable portion of the year. It also explains the much publicised high speed of construction work in U.S.A. because the short construction season necessitates high working speed to complete projects in a reasonable span of time and also, construction organisations have a compulsory and lengthy period to refit and to plan for the next season's work. Both the high construction speeds and the elaborate and expensive pre-planning are necessitated by the short construction period. High speed construction work is inherently expensive as it requires large-scale provision of men and plant and thus any hold up on the job such as shortage of material or breakdown of machines or any poor organisation of work will result in an elaborate construction organisation working in an expensive condition of inefficiency. A proportionally large and experienced engineering organisation is required to back-up the construction force. It is well to be aware of the background to the high speed construction work in the U.S.A. and to realise that the construction season in Australia is 12 months of the year and that projects can be completed in the same calendar period as in North America but at half the working speed and at lower cost.

Political Factors

The one that occurs to mind immediately is import restrictions and the encouragement of local industry in economically young countries such as Australia. This results in high internal price levels for many manufactured goods and, if the policy is extended to basic materials, may restrict the possible range of manufacture. For instance, all commonly used plastics are made in Australia under protected conditions and the industries using plastics must firstly pay more for them than overseas factories and, secondly, do not have access to the same variety of type and grades of these plastics. The local manufacturer is placed at a disadvantage on both accounts.

By contrast, in England and Germany traditional exporting nations, attention is paid to assisting the export industry; hence, this Department has access to the engineering data of the British and German Post Offices. As a specific example, all research work done by the German Telecommunication Industry is charged as overhead on local orders only. Export orders are not charged overhead for research. This is an agreement between the Bundespost and the industry for the express purpose of helping the industry in the export market.

A most interesting case in regard to political influence is the development of styroflex type carrier cable in Germany after the war. This happened because the Armistice forbade T.V. in occupied Germany. The ban extended to T.V. frequency amplifiers and hence coaxial cable installations were not permitted. The rising demands for trunk line facilities, therefore, led to the development of the 120-channel per pair styroflex insulated cable. This cable is unique to Germany and may never have been developed had technical issues only been involved. Further, when the T.V. ban was relaxed, an extensive Broadband Radio Programme was put in hand partly because this was the fastest way of providing large blocks of telephone circuits and T.V. relay facilities at short notice; secondly, at the time (about 1951) current technical opinion was that radio systems had made trunk cable systems obsolescent—a view which has since changed completely.

An important political factor is whether the telephone service is publicly or privately owned. Where it is under Government ownership it is traditionally a Department of the Central Government. As such it enjoys considerable legal privilege and its operating charter and regulations (i.e. the Act and Regulations under the Act) have legal precedence over those of other public utilities, the order of priority being Federal or Central Departments, Federal or Central Instrumentalities, State or Regional Departments, State or Regional Instrumentalities, Local Government organisations and privately owned enterprises. This legal privilege gives the Post Office telephone service substantial advantage over the privately owned system, which reflects in technical practices but it also makes them directly subject to the Central Government financial policy.

To quote some aspects where the privately owned Bell System suffers in comparison with the Post Office telephone systems:—

1. The acquisition of sites, properties wayleaves, etc. is strictly a private business transaction between the System and the property owner and the System can be held to an exhorbitant price for an essential site.
2. Local Governments place restrictions on such matters as the routing and alignment of duct systems, the siting of public telephone cabinets, etc.
3. Interference to telephone circuits by power circuits is a chronic problem everywhere. In Australia and the U.K. however, the operations of Power Authorities are governed by Regulations designed to reduce interference to a minimum and the Power Authority must build and operate its plant to conform to the requirements of the Telephone Authority. By contrast in the U.S.A., Power Authorities are under no obligation and the Telephone Authority may have to take elaborate and expensive precautions to protect its plant from power interference..
4. Telephone charges and conditions of service are determined in the U.S.A. by a large number of Regulatory Commissions. The Bell System is put to considerable expense in dealing with Regulatory Bodies. There are substantially more Regulatory Bodies than Bell Operating Companies, they are not obliged to follow the same principle and one Company may find itself dealing with several Regulatory Bodies each with its own individual rules. Government telephone systems are subject to parliamentary control but appear to enjoy considerable autonomy in detail matters. In the U.S.A., however, the Bell System is regulated in detail—for instance, in some Regulatory areas they are obliged to furnish party line service on demand even though this may militate against economical plant design.
5. The Bell System does not enjoy a legal monopoly of communications. This can be a matter of serious conse-

quences; for instance, the System is attempting to legally restrain long distance road hauliers from installing their own point to point fixed radio telephone service which they will use in place of the trunk line service.

The Bell System is a highly profitable organisation, and is regarded by investors in the U.S.A. as a stable and ably managed enterprise. A.T. & T. shares are regarded as a first-class investment. Consequently, the System can always raise funds on the money market. Further, due to the profitable nature of telephone business, the System is always looking for means to employ more funds. Hence, Bell System policy is to provide plant in advance of demand. The effectiveness of this policy is illustrated by the fact that orders for new residential services are normally issued immediately on application without checking first that plant is available. There is a certain degree of "calculated risk" in this policy, but difficulties rarely occur. For instance, in travelling through widely separated areas, in the U.S.A. and Canada, aerial line plant can be seen installed and ready for service in new housing estates, well in anticipation of occupation of the houses. Quoting actual figures for the Illinois Bell Company (State area), in 1952 the Company had 900,000 main stations, and 9,000 "Held" orders (deferred applications in our phraseology). In 1959 it had 1,270,000 main stations and only 1,900 held orders.

In England and Germany funds for telephone service are restricted as in Australia under a general anti-inflationary policy of restricting public works expenditure. This consideration, of course, does not apply with the privately owned Bell System, and it might appear that private ownership does provide funds for telephone service if the service is profitable, and if the money-market is prepared to respond to call on it for such funds; whereas a Government telephone authority under similar circumstances is restricted in funds by reason of general Government policy. However, this conclusion may not be true. The telephone service in North America is excellent and is always available, and this possibly is primarily due to the great economic strength of that country. Briefly, the country can afford the luxury of a first-class telephone service, whereas other countries cannot. Their first-class telephone service, is probably a reflection of economic strength, and is not a question of Government versus private ownership. This point is mentioned because the Americans make a feature of private ownership. Other public utilities in the U.S.A. owned by private capital, particularly transport services, compare unfavourably with Government-owned services in Europe and Australia.

A result of the ready availability of funds in the Bell System is that works are planned in the most economic possible way balancing immediate capital expenditure against operating and maintenance costs of the facility over its life. In the well-managed Bell System it can be safely assumed that the method of providing a facility where several alternative methods are available is determined strictly on the basis of Economic Comparison. By contrast Government telephone authorities, restricted for capital funds, must tend to do works in a way which makes least call on their capital resources. An amusing sidelight on the funds position in the Bell System is that individual engineers tend to charge as much expenditure as possible to Capital Account, which is freely available and to charge as little as possible to the Maintenance Account (which forms part of the Profit and Loss Account). The latter account is strictly policed and a field engineer is judged by comparison between his plant fault record and the expenditure on maintenance.

A positive factor in Bell System policy appears to be fear of Government ownership. To quote an example, the Telephone Division of the Rural Electrification Administration, which has a specific task to upgrade telephone service in rural areas has had the effect that the Bell System apparently no longer seeks to make a profit on its rural operations. Further, the System feels obliged to provide a good class of rural service because its view is that if the Bell System does not, then the Government will, and this will be "the thin end of the wedge" for Government ownership generally. Their views are influenced by the difficulties of the privately owned power industry in the U.S.A.

The situation is even more marked in Canada, where the Bell System has the 'taint' of American capitalism about it and is, therefore, unpopular on National grounds; and, secondly, because in Canada there are some first-class Government-owned utilities such as the Ontario Hydro-Electric Power Commission, whereas in the U.S.A. Government services have the reputation of being poorly operated. For instance, the U.S. Post Office, from the point of view of a superficial customer, appears to be poorly run and the Bell System points to such examples as the fate that could overtake the American Telephone Service if it were Government run. However, the Canadian Bell cannot point to any such example. Some years ago in Toronto in new housing developments the Government-owned electricity, water supply and sewerage utilities were able to provide service in new housing developments ahead of occupation, whereas at the time there was a lag of up to two years in the provision of telephone service. Canadian Bell, therefore, exerted all its resources to overcome the situation because of this fear of Government ownership.

The System is very sensitive to public opinion and goes to considerable lengths to forestall criticism. Surprisingly a great deal of criticism of the System is to be heard in North America; most of it is ill-informed and unfair as the System provides a first-class service at, by American income levels, low rates. The type of criticism was much as would be expected in Australia but more intensified.

Ownership of the Telephone Manufacturing Industry

Three separate cases must be considered:

(i) The operating authority designs and manufactures the bulk of its own plant and equipment. The Bell System is probably the only case.

(ii) The operating authority buys equipment designed and manufactured by a national telephone equipment manufacturing industry. This is the position in England, Germany and Sweden and other parts of Europe.

(iii) The operating authority either imports its material or else buys it from local factories which make to overseas design. This is substantially the position in Australia.

The fact that the Bell System also designs and makes its own plant has some important influences on costs and design, for instance, the optimum balance in design can be struck between manufacturing costs and user costs (that is installation and maintenance costs). Where the telephone authority buys from a separate manufacturing industry there must be a tendency for the authority's specifications to be drawn up largely with installation and maintenance requirements to the forefront and manufacturing considerations overlooked to some extent; and where the operating authority buys from an overseas manufacturer there must be tendency for ease of manufacture or the requirements of the manufacturer's major customers to take precedence over the buyer's operating and maintenance costs. Whether manufacturing or user considerations take precedence will depend on the cussomer's strength as a buyer as well as his ability to specify his own requirements correctly. The Bell System is in a position to strike the best compromise between these conflicting requirements.

Another aspect is that since there is no competition in supply the manufacturing plant can be run until it reaches the end of its economic life. At this point new plant is installed using the most modern techniques and the product design is suitably altered to take best advantage of the new manufacturing techniques. New developments are only introduced when proved economic on the basis of all manufacturing costs including investment in manufacturing plant which will be rendered obsolete by the change as well as all conditions relating to use in the field. Sound designs are not prematurely scrapped to meet a competitive situation.

As both maker and user the Bell System obtains its apparatus under probably the most favourable possible economic conditions. However, there must be a tendency to defer the latest developments for the time being until the appropriate interval in economic overall planning. Furthermore, a lack of competition exists which must to some extent tend to make design less progressive.

The telephone authority which buys from outside, buys on a competitive market and enjoys all the advantages of competition including the ability to buy the latest development at the earliest stage. Even if the telephone authority must buy from its national industry and there is no internal competition, there is intensive competition with other countries for the export market which ensures that the industry remains technically progressive even if there is no price competition in the home market.

A reasonable conclusion to be drawn is that the Bell System practice in regard to plant design may be somewhat conservative but that it preserves the best balance between manufacturing and user costs. It should always be kept in mind, however, in examining any Bell System practice that the association of the Western Electric Coy. and the Bell System will result in a different approach to the design of items of plant in which manufacturing aspects of the design are given more weight than when the item is designed by an authority whose main interest is in operation and maintenance.

Australia and Canada differ from the U.K., European countries and the U.S.A. in that there is no national telephone manufacturing industry—while most requirements are made in Australia they are to overseas designs and patents and the industry is partly overseas owned. One result is that there is more freedom of choice of design than in the case of overseas administrations. For instance, it would hardly be conceivable for the B.P.O. or Bundespost to adopt the Swedish cross-bar technique and ignore the technical developments and the patent pools of the national telephone industry; the freedom of technical choice of a Government telephone authority must be limited by the manufacturing and research capacity of its home industry and their current investment in manufacturing plant and ownership of patents.

One conclusion reached overseas is that this Department is one of the largest uncommitted customers in the world and that its business is eagerly sought by the British and European industry both for its volume and also because its technical prestige is sufficiently high that its choice of design influences other customers.

Technical and Administrative Complexity

Recent technical development such as the Broadband Programme, the E.L.S.A. and A.N.S.O. schemes and the crossbar project are regarded by engineers as heralding a new era of "technical sophistication". By comparison with the Bell System, B.P.O. and Bundespost, however, Australia is "technically unsophisticated". One result is that developments and modification to existing plant and equipment can be effected simply and without undue complexity whereas small technical changes in the more complex overseas telephone systems must be closely and cautiously examined for side effects. Another probably consequential result is that these three authorities have proportionally much larger technical headquarters staffs.

Another factor is the comparatively small scale of organisation in Australia. The Bell System and the Department are organised along similar lines except that there are three tiers of authority in the Bell System—the Operating Company regional organisation, the Operating Company headquarters, and the System headquarters (A.T. & T.) — compared with two—State Administration and Central Administration. Further, the scale of magnitude is perhaps in the ratio of thirty to one. Consequently there is much more opportunity in Australia to collect information, make decisions and put them into practice quickly and accurately. This is the advantage of a small organisation. By reason of the complexities due to sheer size the Bell System must be slow moving and cautious and give the appearance of being conservative. Similar remarks apply to the B.P.O. and the Bundespost except that they are smaller in volume and territory than the Bell System and consequently can operate with somewhat more speed and flexibility.

The conclusion is that the large overseas authorities must be more cautious and slow moving than we are in technical matters and the fact that the Bell System or B.P.O. has not adopted a new practice is not necessarily a good reason why we should wait—it may merely be that administrative difficulties are delaying its investigation and introduction.

AUSTRALIA & NORTH AMERICA

General Conditions

In spite of being aware of the dangers of uncritical acceptance of overseas matters it is difficult for an Australian visiting U.S.A. and Canada for the first time to avoid being so impressed by the general similarity of the three countries to such an extent as to unduly influence him towards North American techniques. This is particularly so if he is returning to Australia after a visit to the U.K. and Europe where customs, ideas and conditions are obviously very different from those at home. The Australian landing in the U.S.A. after a period in Europe feels so much at home that he is bound to be biassed towards American ways. These are the views not only of the writer but of every experienced person with whom he has discussed the matter. Since Australia has so much in common with U.S.A. and Canada their methods and techniques must often be eminently suited for use here. But there are sufficient important points of difference to make the uncritical acceptance of American ideas a dangerous procedure.

The first important aspect of similarity between Australia, Canada and the U.S.A. is the large physical area of these countries compared to European countries.

Secondly, these three countries are new countries. For instance the modern development of U.S.A. commenced with the opening of the West and the inauguration of large scale migration, after the end of the Civil War in 1865. Australia's growth commenced about the same time with the discovery of gold. Thus both countries grew in the age following the Industrial Revolution and the previous era has left little mark—this, for instance, is probably the reason why Australian cities appear so similar in character to American cities and both seem so different to English and European cities. As a result there is little tradition in either country and people are probably more open to new ideas and new techniques.

Neither country has suffered modern war on its own soil, a factor which, particularly after seeing the results of war damage in Europe and England, must have a profound effect both on the economy and the outlook of the people.

Another factor is that the economy has been consistently expanding for a century in both countries and there has always been scope for application of new techniques and practices.

While an Australian feels at home in the U.S.A. and life in both countries is similar in many ways it is not correct to say that Australia is "Americanised" —it is rather that both are New World countries and the customs, manners and problems in each are those of the New World. There are, however, some very important differences between the two countries which must be taken into account.

The first point is the great economic strength of the U.S.A. The wealth of the U.S.A. is well known and much publicised in terms of statistical data but first hand observation is necessary to really appreciate the position and to quell any scepticism that may be felt about the statistics. Quoting some diverse examples:—

1. High incomes combined with low costs of living. For instance, engineers at A.T. & T. Headquarters, New York equivalent to Sectional and Divisional rank, are paid \$18,000-\$21,000 and \$15,000 (£A6,700) per year respectively. These are good, but not exceptional salaries. Their living expenses, for equal standards, would not be much higher than ours.

2. A flight from St. Paul to Denver, a distance of about 700 miles across the heart of inland U.S.A. was over fertile farm country for its full distance. A similarly placed flight in Australia would be from Alice Springs to Kalgoorlie across barren desert country. The U.S.A. is endowed with a rich soil, adequate rainfall, a temperate climate, as well as with great mineral and other resources —it is a country richly endowed by nature.

3. It is most impressive in the Bell System to see the number of Engineers who can be directed to work at a single task. Proportionally more Engineers are employed in England, or Germany than in Australia, but, it is clear that the Americans can and do put far more professionally trained men on to a given task, then either England or Germany or Australia.

However, there is a wide disparity between the economic strength of the different parts of the U.S.A. and while the

Northern and Pacific coast States are undoubtedly the most prosperous areas in the world the Southern States are comparatively weak economically. These comments apply to the North.

Another factor is the comparatively small population and relatively immature economy of Australia. This has many effects, one being that there is not the weight of demand for service that there is in the U.S.A. and another being that Australia's resources have not been developed to the extent required to meet the demand.

Conclusions to be drawn are that needs for service in the two countries may differ in both type and intensity, the economic way of meeting them may be different and finally types of services which can be provided in the U.S.A. may not be feasible in Australia due to our inferior economic position.

Availability of Skilled Tradesmen

There appear to be few facilities for training skilled tradesmen in the U.S.A. such as the apprentice scheme familiar in Australia. For instance, the Bell System does not operate anything equivalent to our 5-year training course for technicians or even the shorter course for training linemen. Craftsmen are recruited directly from school and are trained almost entirely on the job with short classroom sessions from time to time. This is typical of American methods as a whole and has the repercussion that trade skills are highly valued in the U.S.A. In fact, when enquiring as to how such skills as toolmaking are acquired a satisfactory answer could not be given, but it was suggested that most of such tradesmen are migrants from England and Europe.

This lack of a force of skilled tradesmen has an important repercussion on plant design in that every effort is made to "deskill" field operations in the U.S.A. As much of the installation complexity as possible is taken out of the task by designing the item so that most of the skilled work is done in the factory and installation becomes largely a simple attachment task. This approach also explains the high degree of specialisation by workmen in the U.S.A. Under the apprentice training scheme the tradesman is trained in every branch of his craft particularly in the first principles whereas under the American scheme tradesmen are trained to be skilled for the task in hand and nothing more.

Side by side with this absence of a large body of skilled workmen is a relative abundance of engineers so that technical practices and designs can be carefully and elaborately engineered and made suitable for use by a relatively unskilled body of workmen.

Hence it follows that many American designs and practices are unsuited for Australian usage because of the difference in the proportion of engineers to skilled workmen here.

SIZES OF EXCHANGE AREAS IN NORTH AMERICA

It is generally known in Australia that the sizes of telephone exchanges and exchange areas in North America are substantially larger than we are accustomed to. Nevertheless, it is surprising to find in suburban areas similar in appearance to Australian suburbs, how few exchanges there are in the area and that these are mainly very large exchanges. For instance, the Evanston district of Chicago is an urban area very similar in social, commercial and residential development to the eastern suburbs of Melbourne. A comparison of the exchange sizes is illuminating.

Melbourne

W Group (Note 1)

Box Hill	9,354
Camberwell	4,685
Canterbury	7,004
Deepdene	3,521
East Kew	5,097
Hawthorn	4,852
Kew	3,442
Mitcham	2,749
Nth. Balwyn	1,780
Ringwood	3,268
4 small exchanges	1,338
	47,090

Chicago

Evanston District (Note 2)

Evanston	29,662
Wilmette	9,334
Winnetka	10,050
	49,046

Note 1.—Subscribers connected at 30/6/59.

Note 2.—Subscribers Pairs Terminated at M.D.F., December, 1958. The term "Subscriber Pairs Terminated" means the number of working subscribers' lines appearing on the line side of the M.D.F. Because of the widespread use of party lines the actual number of working cable pairs terminated may be substantially less than this figure.

The three Chicago exchanges serve an area about 10-12 miles long and 4 miles wide with a population of about 105,000. The W group in Melbourne is somewhat larger in area and population. Evanston is part of a Bell System administrative area (the North Shore Division) where there are 10 exchanges (including the 3 quoted above) with 193,950 subs. pairs terminated.

Another example is Chicago Heights exchange with 15,830 working subscribers' pairs terminated. The exchange area is roughly triangular in shape the base being about 13 miles and the height about 7 miles. It is a newly developed residential area with a large amount of still undeveloped land. The developed area is scattered amongst the undeveloped areas. Ultimately, it is expected that the whole area will become one large suburban residential development. As a matter of interest, it includes the suburb of Park Forest, described in William H. Whyte's book, *The Organisation Man.* The exchange is approximately in the geographical centre of the area, but not the copper centre and is about 15 miles from the centre of "down town" Chicago.

Another example was an exchange area in a country district which the Bell system had recently taken over from an independent Company. The plant was in run-down condition and the Illinois Bell had virtually started from new in rebuilding it. The area consisted of a country village, and surrounding farming population. One exchange only was established in the village to serve the exchange area which was over 200 sq. miles in size. Farm houses up to 12 miles from the exchange were served by loaded 20 lb. cable. Under Australian practices cable would be used for three or four miles, then aerial construction to meet transmission requirements or alternatively several R.A.X.'s would be established to serve the area in addition to an exchange in the town.

The following data is an analysis of exchange capacity for the State Area of the Illinois Bell Telephone Company at December, 1958:—

Number of subscriber's lines:	1,245,000
Number of subscribers' pairs terminated on exchange M.D.F.'s	1,066,000

(The difference between the two figures is due to the use of party lines. If there were no party lines, the two figures would be equal.)

Number of Exchanges:

Subscribers' Pairs Terminated	Number
Under 100	13
100- 1,000	87
1,000- 5,000	58
5,000-10,000	23
10,000-20,000	21
20,000-30,000	10
30,000-40,000	5
	217

Largest Exchange, 38,570 Subs. Pairs Terminated.

Smallest Exchange, 22 Subs. Pairs Terminated.

There are 36 exchanges with over 10,000 Subscribers' Pairs Terminated each and totalling 869,500 Subscribers' Pairs Terminated.

Some comparative figures for Australia at 30/6/59 are:—

Subscribers connected to automatic exchanges	1,054,517
Exchanges—	
Standard auto	435
Rural auto	1,213

Thus, for approximately the same number of subscribers there were 1,648 exchanges compared to their 217. The population density of the Illinois Bell area is very much greater than in Australia, being that of the urban areas surrounding the City of Chicago together with well settled farming country; nevertheless, a fundamental difference is revealed in the approach to the problem in the two countries.

Exchange Loops. It is evident that these must be longer than in Australia. Recent statistical surveys by the Illinois Bell in an inner area Chicago exchange showed that the average length of subscribers' loop was 7,700 pair feet and in two large country towns 11,000 pair feet and 9,500 pair feet. A similar investigation made in 1957 in Australia gave the average at 5,280 pair feet (Metropolitan Areas).

Thus there are two aspects of the difference in approach:—

1. The number of subscribers connected to an exchange is greater in the U.S.A.
2. The size of the exchange area is also greater.

The two aspects are, of course, compatible.

Although statistical data is quoted only for the Illinois Bell, from observations in other cities and from discussion, the figures are typical of Bell practice. There are no particular technical reasons for the difference between exchange sizes in the two countries. It is true that extensive loading of subscribers' cable is practised in the United States compared to Australia and also that the dialling loop resistance limits are higher than in Australia, but these factors only affect the fringe areas of exchanges and are not important reasons for the difference.

In discussion appropriate engineers in the Illinois Bell Company could not give any explicit reasons for the large size of exchanges beyond saying that it had always been so and that this was the most economic way of providing service.

Possibly an important factor is that the Bell System is privately owned and lacks any special legal privileges. By comparison the Australian, British and German Post Offices enjoy considerable legal privilege by virtue of the fact that they are central Government Departments; further, they are not subject to the rules of local and regional administrations. This effects the relative economic positions as follows:—

1. The Bell System cannot compulsorily acquire exchange sites but must buy them on the open market at the vendor's price.
2. The Bell System has to pay rates on its buildings. Apart from the fact that Government systems do not pay rates at all, these are higher in the United States because of the wide functions of local Government there (in particular law and order and education).
3. The Bell System is restricted in the location and route of its duct runs by municipal authorities.

Furthermore, the need to build Post Offices in every main business centre means that space is incidentally available for telephone exchange purposes.

These restrictions have the effect that the Bell System will be reluctant to own more exchange property than absolutely necessary. Thus fewer and larger exchanges are indicated. This has the advantage then that, as the copper centre of a large exchange area is less precisely defined than that of a small exchange area, there is a larger choice of suitable exchange sites and therefore more chance of acquiring a suitable site at the market price and less chance of being charged an exhorbitant price for the desired block.

Another factor is the high wage rates combined with low costs of factory made goods in the U.S.A. which make large exchanges more favourable in America. In regard to exchange equipment, one large exchange in lieu of several smaller ones centralises maintenance and reduces the size of maintenance staff. Furthermore, fewer manhours are required to build one large exchange than several small ones and a greater proportion of unskilled labour can be employed. Centralising exchange construction increases the scope for mechanisation and the use of labour-saving devices at which the Americans are so adept.

As regards external plant, conduit costs in the U.S.A. probably favour large exchanges. Conduit construction is restricted by our standards due to wide use of aerial cable, and is mainly confined to the areas in the immediate vicinity of the exchanges. Construction costs are high as the work is mainly in congested areas where hand labour must be used. Further, due to Local Government rules, the cheapest route cannot always be followed and the conduits must be laid deeply in the roadway.

This favours large exchanges, firstly because maximum size cables are used and therefore maximum utilization is made of the ducts and secondly they require very large duct runs which are the cheapest to construct per duct since the cost of digging the trench and refilling it and reinstating the roadway increases much less than proportionally to the increase in the number of ducts.

On the other hand cable costs favour small exchange areas. Labour costs of cable installation are probably similar irrespective of whether an area is served by one large or several small cables. However, heavier gauge of cable is used in the case of one big exchange and total cable costs are much greater as a result. In fact, under transmission conditions common to all local exchange areas, doubling the radius of the exchange area will quadruple the costs—costs increase as the square of the increase in the radius.

To assess the relative importance of costs the following is the latest data available for Australia:—

1958-59 Cost of Subscribers' Services.

Metro. Auto	Providing			Maintenance		
Exchange Equipment	68	2	2	5	14	6
Subs. Equipment	15	4	1	1	8	0
Cables and Conduits	138	16	0	3	6	7
Aerial Wires	18	0	11	1	1	0
	£240	3	2	£11	10	1

It will be noted that Cables and Conduits make up the bulk of the providing costs, but Exchange Equipment makes up the bulk of the maintenance costs.

From the discussion above it is plain that both the ratio and magnitude of the different items listed above would be altered if assessed in terms of American costs and price levels. The ratio of internal and external plant costs in Australia arises largely from the sizes of particular exchange areas which are determined in metropolitan areas by economic comparisons in every case. The usual process is that a demand for telephone service arises on the outskirts of existing exchange areas due to the development of previously unoccupied land. This demand is initially met by providing more cable back to the existing exchanges. This cable must be heavier gauge than existing cables to provide standard grade of transmission for these more distant services. Eventually, as the demands for service in the new area increases the costs of extra cable and conduit become so high that it is cheaper to establish an exchange to serve the area. The decision to establish the new exchange is based on an economic comparison of capital and annual charges for internal and external plant of serving the area from existing exchanges compared to establishing the new exchange. It is the rising cost of line plant to serve the new area which first shows the need to investigate the economics of establishing a new exchange.

Thus there is a logical economic basis for the ratio of internal and external plant costs in Australia although the correctness of the ratio is effected by the difficulties inherent in economic comparisons which are necessarily spread over a number of years due to changes in the value of money, to changes in the relative price levels of different items of plant and labour and to changes in technique.

A comparison between the economics of Australian and American practice would require a breakdown of American costs between labour and material. An accurate knowledge of building and equipment costs and of manhours required for plant installation would also be necessary. It might be possible then to draw a comparison between the economics of the practices in the two countries and it is likely that the comparison would prove our practices correct under the Australian cost structure and the Bell System correct under U.S.A. costs. The required data is not available but it should be obvious that any proposed changes in present practice to bring it more in line with American practices must be approached with great caution and all the relevant cost factors in the U.S.A. ascertained and their importance assessed.

Apart from the reasons given above it is possible that the large exchange areas in the U.S.A. are based on practices developed in pre-war years. It is stated that the move to the suburbs is a relatively recent one and that the bulk of the urban population formerly lived in apartment house areas of high population density. (King's Cross, Sydney is the only area in Australia similar to the types of such areas to be seen in the inner parts of New York, Chicago and San Francisco). The area density of telephones in these localities was very high and very large exchanges serving relatively compact areas were required to serve them.

Furthermore, the present suburbs grew from a nucleus of small towns spaced some miles apart on the periphery of the metropolitan areas. The suburbs grew by filling up the open space surrounding these towns until the developments met to form one continuous urban area. The suburban development in Australia has not been of this type; rather the boundaries of existing suburbs have moved further outward in a continuous development although the American pattern can be seen in the way that Dandenong is becoming part of the Melbourne urban area and Gosford appears likely to become a dormitory suburb of Sydney. A result is that the areas served by existing exchanges in these U.S.A. towns grew out as the suburbs grew just as the areas served by country towns in Australia tend to grow. This is the case in the Evanston exchange area quoted above.

Summarising this discussion, in both U.S.A. and Canada the service areas and the number of subscribers connected are substantially larger than in Australia. The reasons probably include the factors which make it desirable for the Bell System to own as little exchange property as possible, the relative scale of wages and material costs in North America, and some historical factors which do not exist in Australia.

The effect of large exchanges and exchange areas is almost certain to reduce equipment providing and maintenance costs, but line plant costs will increase substantially because heavier gauge cable is required to meet transmission limits and the average length of subscribers' lines is longer.

The relevant factors in the two countries are so difficult to assess and compare that great caution must be exercised and a careful assessment of the economics made before changing our present scale of exchange sizes. As exchange areas in Australia have been determined primarily on the basis of economic comparison it is very likely that they are the correct size for Australian economic conditions. It is to be expected, however, that wages will continue to rise relative to material cost and this may tend to make the preferred size of the exchange area larger.

EXCHANGE BUILDINGS

Exchange buildings in the U.S.A. are similar in general design and appearance to Australian exchanges, particularly suburban exchanges. The ground floor contains the M.D.F. test desk, staff amenities, etc., and the equipment is housed on the floor above. In visiting crossbar, panel type and Strowger exchanges the general layout in each case was a familiar one.

There is however, one important point of difference—all these buildings have large basements. This is normal building practice in the U.S.A. because of climatic conditions. This basement housed the power and battery equipment. The power equipment appeared familiar, but in every case enclosed type cells were used and the batteries were not partitioned off from the rest of the basement which was, in fact, one large room. In some cases there was a brick partition along one wall to form a separate cable chamber but in other cases the cable racking was erected along one wall of the basement and was not partitioned off from the plant in the basement. An important point to mention is that cable entry is by ducts and all the ducts are carefully sealed off so there is no question of water or gas entering the basement through the duct.

One exchange building only was visited in Germany. It was a combined exchange, carrier station and district office. The exchange equipment was E.M.D. type and the interesting point was that the switches were in a separate sealed room served by a packaged air-conditioner; staff enter this room only for specific purposes such as routines and attention to faults. The M.D.F. and the test desk were side by side in a room in another part of the building. The exchange itself was of about 2,000 lines capacity. This approach seemed a reasonable one in that the switches are confined to a small air-conditioned space from which the staff are excluded as far as possible.

PARTY LINES IN THE U.S.A.

The Bell System provides 2 party and 4 party line service with harmonic ringing in urban areas in addition to rural party line service with code ringing. The party line service is a non-secret type and there is nothing similar to duplex in use. The party line system which has been widely used in urban areas appears to be a trouble to the Bell System, which is forced in some areas by the Regulatory Commission to provide party line service on demand by applicants; a steady demand exists because party line rent is lower than exclusive service rent. Nevertheless, as would be expected, there are a diminishing number of party line services in the urban areas and the operating Companies are put to some trouble to insure that a 4-party line service, say, has 4 parties on it and not a lesser number; obviously they are faced with a difficult commercial situation if people paying rent for a 4-party service are only sharing a line with one or two other subscribers. The result is that the subscribers to a party line may be widely separated in the exchange area and a difficult problem in cable design arises, particularly in resording and re-arranging cable pairs. In discussion with American engineers, it appeared that the Bell System would prefer not to have party line service in urban areas.

PROCEDURE FOR INSTALLATION OF SUBSCRIBER'S TELEPHONE SERVICE

These are generally similar in Australia, Germany, U.K. and U.S.A. In each country application for a private subscriber's service is made at a Commercial Office where a multi-copy Telephone Order form is prepared listing particulars of the subscribers's requirements. Exchange number and cable pair allocations are made by appropriate plant offices and copies of the Telephone Order complete with installation data go to the Installation and Exchange staffs. On completion of the works, costs and statistical details are added and copies of the Order are distributed to Accounts, Directory, etc. Both the B.P.O. and Bundespost forms are similar in appearance to the Australian Telephone Order.

One difference to Australian organisation in these countries is that the one staff completes the work at the subscriber's premises; separate line and substation installation staffs are not employed. An exception to this rule is made by the Bell System when installing large numbers of services in the one area such as new house developments—in this case the Task Force principle is used and separate teams are employed for inside and outside work.

In the Bell System preparing and moving copies of the Order quickly to the destinations is a problem which has been closely studied by the Bell System and the latest procedure used is for the Business Office, Plant Service Centre, Revenue Accounting, Directory and Traffic Intercept to be connected to the one teletype circuit. The Order is prepared in the Business Office, the exchange number and pair allocation being passed over the teletype circuit from the Plant Service Centre, and is then distributed to the field staff. The aim in Metropolitan areas is to provide a "one day service" which means that if a subscriber applies say on Monday P.M. the Order is in transit on Tuesday and copies are in the hands of the M.D.F. and Installation Foremen by the close of business Tuesday. The M.D.F. jumper is run on Tuesday night and the Installer is given his copy of the Order when he reports for duty on Wednesday morning. He will report to the applicant's premises at any time on Wednesday that the applicant cared to nominate to the Business Office; he completes the installation at the one visit. Note that the designation "one day service" is a slight exaggeration. Had the applicant applied on Monday A.M. the service could have been installed on Tuesday P.M.

The Bell System, as part of its service to customers, puts great store on completing the service by the time promised and statistics on the subject at A.T. & T. Headquarters showed that 98% or better were completed by the promised date which means, in most metropolitan cases, "same day" or "one day" — a very impressive performance. About 60% of Orders, taking the System as a whole, are said to be completed on the "same day" or "one day", basis. One factor that helps is that the Business Office assumes that a cable pair and an exchange number are available and accordingly quotes the application on the spot. The Office has a list of barred areas where service cannot be quoted on demand, but everywhere else it is assumed that line plant is in situ to provide the applicant's service. Experience is that this policy involved only a slight risk. As there are now few barred areas it is evident that many applicants are connected one or two days after they apply.

Other reasons for this promptness, apart from the ready availability of capital and hence of plant, are:—

1. The one Supervisor controls the work at both the exchange and subscriber's end.
2. The use of a lineman installer associated with a form of outside plant construction which allows one man, by running a length of drop wire, to complete the line work. I.T.P. construction used in many parts of Australia is similar.
3. Pre-jumpering at the M.D.F. is done the night before.
4. All testing of the installation is done by the installer using a simple battery operated tester and an exchange ringback type test. If any component is faulty he faults the whole installation and leaves the premises. The new service is then treated as a faulty line and handled through the fault procedure.
5. Paper work is kept to a minimum by the installer reading his completion data to a female clerk or into a tape recorder at the Plant Service Centre. He does not submit a written completion Order.

The exchange Test Desk does not check any new private subscriber's service. It is employed for maintenance and fault testing only. This procedure was introduced some years ago as a stop gap due to shortage of staff and equipment, but testing by the Installer proved satisfactory and the saving in staff, equipment and exchange space is such that the previous procedure, the same as present Australian procedure, was not re-introduced.

Another important factor is the positive drive to ensure that all work is completed on time. The efforts of all persons involved in these operations is measured and examined by their superior on the basis that every person must complete a certain proportion of his work on the day it is received and is only permitted a certain carry-over to the next day, e.g. the Business Office must clear say 90% of its orders on the day the application is made and a continuous critical record is kept of its performance.

The procedure in Germany is that the Commercial Office contacts the Cable Recorder by telephone while the applicant waits at the counter and, if a line is available, the Order, complete with installation data, is prepared immediately and posted to the installation staff. The Bundespost claim that 40% of all applicants have service within five working days.

In England the average time for completion of order work in London is three weeks in the Sales Division and four weeks in the Engineering Division. In the Provinces 60% of Orders are completed within one month, the majority being within 2-3 weeks.

Corresponding data is not available for Australia, but it seems unlikely that the performance would be as good as any of these, even for areas where both exchange numbers and cable pairs are available. One reason is probably the use of two separate staffs to complete work at the subscriber's end. In the other systems time is lost at two stages—one is in the paper-work which is unavoidably complex resulting in a delay before the Order is in the hands of the Installation Staff. The other is the staffing delay before the work force arrive at the subscriber's premises. In the Australian system a third delay is involved while notification is passed to the Internal Staff that linework is completed and finally there is the delay before the Internal Installer arrives at the subscriber's premises.

Particularly by comparison with the Bell System there seem a lack of positive drive to expedite this phase of work which is probably the most important of all in regard to good public relations. Apart from the use of two separate staffs to complete work at the subscriber's end, control of the work, except in Country Divisions, is spread between three different Divisions—Metro. Service for the M.D.F. jumpering and the Test Desk work, District Works for the line work and Subscribers' Installation for the instrument. The lowest common level of authority is the Superintending Eigineer, Metropolitan.

A better arrangement for management would be the one Divisional Engineer in charge of all work external to the exchange and also of work on the M.D.F. This is the arrangement in New Zealand, where the M.D.F. is partitioned off from the exchange and is the responsibility of the External Plant Engineer. If testing is carried out by the installer then all work directly associated with the subscriber's installation would be controlled by one Divisional Engineer.

MATERIAL SUPPLY ORGANISATION

The scale of the problem in Australia is larger than might be expected. England and Germany are territorially small and the material distribution and control problem is simplified thereby. The volume of the material handled in Australia is surprisingly high. Taking subscribers' cable, which is a basic item, our annual requirement is 500,000 pair miles per year and increasing by about 50,000 pair miles per year. The consumption in the U.K. is 700,000-800,000 pair miles per year. Bell System requirements of cable were estimated at 125 B.C.F. (billion conductor feet) for 1959 and 131 B.C.C. for 1960—11.8m. pair miles and 12.4m. pair miles respectively. The relative quantities of cable used in Australia, U.K. and U.S.A. are not proportional to the number of subscribers in the three countries and this suggests that the length of subscriber's loop in the U.K. is less than in Australia and is substantially larger in the U.S.A. than in either —this is undoubtedly due to the large size of exchange areas in the U.S.A.

Figures were not obtained for Germany but the output of the F. & G. P.I.L.C. plant at Cologne is about 350,000 pair miles per year. This is not the total output of F. & G. as they have plants in other parts of Germany. A factory producing 350,000 pair miles is a large one by English and European cable industry standards but Australian factories have a comparable volume of output.

In both the U.S.A. and U.K. the estimating of material requirements is a major difficulty and no completely satisfactory means of doing so have yet been developed. Shortly before I was in the U.S.A. the President of the American Telephone & Telegraph Co. had become so concerned with inaccuracies in forecasts, particularly under-estimates and subsequent shortages, that he had written a personal instruction that material forecasts were to be scrutinised at the highest levels in the Operating Companies (i.e. our State Administrations).

Both the B.P.O. and Bundespost work on negotiated contracts and the administrative machinery for placing orders is simpler than with the public tender system used in Australia. In the Bell System, the Western Electric Co. fulfils the role of Supplies organisation, Stores Branch and major manufacturer and public tender as we know it is not used. There are no administrative or funds difficulties in ordering material quickly. Material is manufactured in Western Electric Co. factories or bought by the Company from outside suppliers to W.E. specifications. Stocks are held at warehouses located at suitable points throughout the country from which the Operating Companies draw as required. Although Western Electric Co. is part of the Bell organisation, it is required to show a profit in its own right and consequently seeks to maintain minimum stock holdings consistent with the ability to supply any item on demand. The inability to supply an item means loss of profit on its sale to the Operating Company as well as the administrative penalties which the System will enforce if the Operating Company is unable to provide service for this reason.

The Bell System uses "long-term estimates" and "short-term estimates" of material requirements. These estimates originate in the Operating Company. "Long-term estimates" cover major works material such as switching plant and large cables which are normally supplied from the factory direct to the job. "Short-term estimates" cover day-to-day requirements of plant items, telephones, pole hardware and the like which are carried in the Western Electric Co. warehouses to meet demands from the Operating Company in the same way as the Stores Branch carries stocks to meet Engineering Division demands.

The short-term estimates are prepared at 3 monthly intervals covering a period 6 months ahead and they cover about 80 "key items" from which are computed the requirements for all items of this type. Statistics of past usage of all items of plant are held by the Western Electric Co. and from them have been prepared tables of usage showing the quantities of all general items required to match the forecasted requirement of key items. However, should the Operating Company expect that for some reason the usage of certain general items will be out of balance with the associated key items then the Western Electric Co. must be notified. The estimate, together with details of stock on hand and estimate recoveries, is forwarded by the warehouse to the W.E. headquarters in New York where it is analysed and a proposed delivery schedule prepared for all items required in the period. This delivery schedule is referred to the region where it is available for examination and approval by both the warehouse and the Telephone Company. It will be noted that the arrangement is similar to the Australian one, except for the accumulation and analysis of data over a lengthy period, which has enabled a few key items to be confidently adopted as a basis for computing material requirements.

THE BELL SYSTEM AND SERVICE TO THE PUBLIC

A strong impression is gained of the desire of the Bell System to serve the public in every possible way. This appears to be typical of American business in such public services as restaurants, shops, etc., where there appears to be a genuine desire to provide good service and it is, undoubtedly, part of the American business philosophy. But the emphasis on service appeared to run deeper in the case of Bell than the normal desire to provide good service for good profit. In fact, the Bell System impresses as having a deep sense of responsibility to the public quite apart from any question of profit.

An impressive example is the efforts just discussed to provide subscribers' telephone service at short notice. Two other items that impressed were the bell on their standard subscribers' telephone and their public telephone set. The bell has a deep melodious ring which can be adjusted for volume from almost silent to a loud clamour. As anyone with a young family knows, this is a valuable feature in a telephone which is also of assistance to the Administration as the subscriber is not tempted to leave the handset off to prevent the bell ringing and disturbing the household. The public telephone had 3 coin slots and no buttons and was simple and easy for the customer to use. By comparison, the 4d. tariff creates an inconvenience because the weight of four pennies is such that an average person may not have four of them in his possession when he wants to make a call from a public telephone and is less likely still to have a further four available if the first call is ineffective. This trouble particularly arises due to the large size of Australian coins compared to American; it is the type of problem which the Bell System would give serious attention to.

It could be stated that the Bell System is "customer orientated" and their whole organisation and outlook is developed so that customers' needs are met speedily and promptly. Although there is an awareness in Australia of this need, the organisation is not geared to meet the customers' requirements so much as to provide administrative efficiency and it could well be re-examined from this point of view.

TECHNICAL NEWS ITEM

NEW METHODS OF RODDING DUCTS

New mechanical and pneumatic methods of rodding ducts are being tested by the P.M.G.'s Department. At present, when cables are to be installed in an existing duct, cane rods with a screwed jointing coupling for each 4 foot length are first pushed in by hand; alternatively, some use is made of a continuous steel wire rod carried on a special reel.

The new methods which are for use for empty ducts are described below:—

(a) Mechanical Rodding

Two truck-mounted "Rodductors" are currently in use on the Sydney-Melbourne Cable Project, and on Primary Works cable hauling activities in Sydney. These units have a magazine accommodating 900 feet of wire rods with a special coupling at each 3 feet. Various rotational speeds are available with mechanical push, and up to 4,000 lb. pull. The rods pass through a flexible metal guide tube with a lining of ¼" spring steel to take the wear. The guide tube is plugged into the duct to be rodded and the machine completes the operation. Various cutters, rod recovery spirals, etc., can be attached to the end of the rods. A crew of two men is used; set up time takes approximately five minutes and a rodding speed of better than 100 feet a minute is achieved.

Ducts obstructed with roots or soil plugs have been rodded without difficulty. These machines appear reliable, but the relatively high cost will limit their distribution and application to obstructed ducts or ducts where pneumatic duct rodding equipment cannot be employed.

(b) Pneumatic Rodding

Six Cope Pneumatic "Fish Line" machines are in operation, one each in Victoria, Queensland, South Australia, Western Australia and two in New South Wales. These units have 1,000 feet of aircraft flexible steel cable, wound on the drum of an air-driven winch. The winch is mounted in a frame on which two concentric tubes are mounted. These tubes are adapted to enter the duct to be rodded. Screwing up the outer tube on the inner tube expands two rubber seals which grip and seal the duct. A projectile with 2 neoprene cups is attached by a swivel to the end of the aircraft cable and by de-clutching the winch and admitting air from a compressor through the unit, the projectile is propelled through the duct at speeds of 200 feet per minute or better. When the projectile reaches the distant manhole it is disconnected and the aircraft cable is coupled to the cable hauling winch line or fish wire. The air winch is engaged and the line is drawn back into the duct. The device works very well in clear sealed ducts but where severe leakage occurs at the joints, as with old rubber ringed jointed ducts, the loss of air pressure prevents the projectile travelling more than one or two conduit lengths.

Obstruction in the duct can block the projectile and cause the air pressure to rise to a dangerous extent, resulting in expulsion of the complete winch unit backwards or blowing up a section of duct if care is not taken to watch the air pressure or stop admitting air if the winch line ceases to run out. In the general case this device provides the most rapid and economical means of rodding ducts used by this Department.

The rodding of ducts in which a cable already exists is a special problem and the most likely machines for this purpose appear to be the Chicago Pneumatic "Electric Mouse" and a very similar unit developed by the B.P.O. and operated by compressed air. These each employ a small diameter vibrating element having a relatively heavy cylinder or solenoid connected to the air line or power cable and a relatively light weight vibrating piston or plunger, having a rounded end. Bristles of inconel wire or nylon are fixed to both the cylinder and the piston. These bristles are set back at an angle of about 45° so that there is little resistance to forward movement, but considerable resistance to backward movement.

INTRODUCTION TO JUNCTION TRANSISTORS

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This series of articles is abstracted from a group of transistor lectures given jointly by the author and Mr. A. C. Luther. The author wishes to acknowledge the fact that many of Mr. Luther's valuable contributions to the lectures have been retained in these articles.

PART III—HIGH-FREQUENCY OPERATION, PULSE OPERATION, AND TEMPERATURE CONSIDERATIONS

R. N. HURST

INTRODUCTION

Previous articles in this series have presented the three basic transistor configurations—the common-emitter, the common-base, and the common-collector—and have briefly described their characteristics. In all these descriptions, it was assumed that the signal frequencies were in the audio region, the signal amplitudes small, and the ambient temperature around 70°F. If any or all of these assumptions are not true, the transistor's behaviour cannot be predicted from the simplified descriptions of the first two articles. This article will extend those descriptions to show transistor behaviour at high frequencies, at high temperatures, and in highly non-linear operation.

Present-day transistors are not capable of providing high-frequency operation and wide bandwidths with the same ease that vacuum tubes can provide such performance. However, proper choice of transistor, transistor configuration and associated circuitry can result in very good video amplifiers and tuned high-frequency amplifiers, with performance equal to that of conventional tube circuits. The circuits and configurations necessary to obtain these results will now be considered.

HIGH FREQUENCY OPERATION

The high-frequency performance of a transistor circuit is strongly influenced by the type of transistor employed. A given circuit will provide widely different high-frequency responses with different transistors. For example, a simple current-driven CE amplifier:

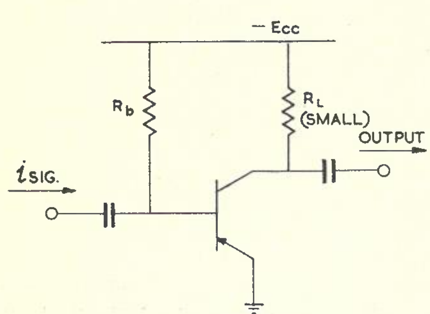


Fig. 125

will provide a bandwidth of about 16 kc for a 2N104; about 120 kc for a 2N219, and about 1700 kc for a 2N384:

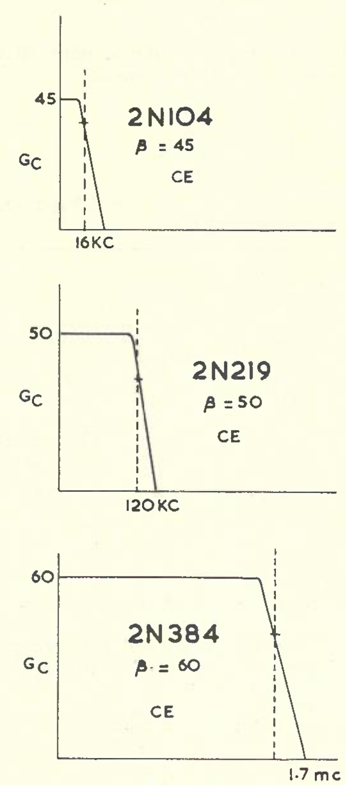


Fig. 126

(These bandwidths ignore stray capacities shunting the load resistor.) Over most of the bandwidth shown, the transistors give current gains of beta—45, 50 and 60, respectively—which fall off to gains of about 70 per cent of beta at the specified frequency. This frequency is known as the *beta cut-off frequency*, f_β, and is an important parameter for describing a particular transistor's potentialities as a high-frequency device.

Much better high-frequency performance can be obtained from a transistor in the common-base configuration:

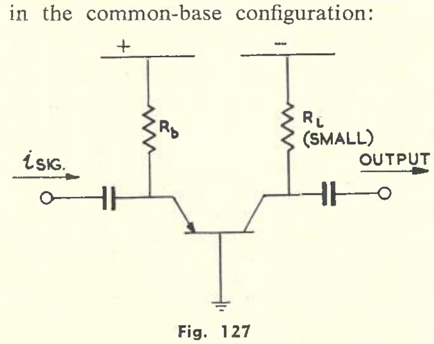


Fig. 127

In this configuration, the 2N104's bandwidth is extended from 16 kc to 700 kc; the 2N219's bandwidth from 120 kc to 6 mc; and the 2N384's bandwidth from 1.7 mc to 102 ms:

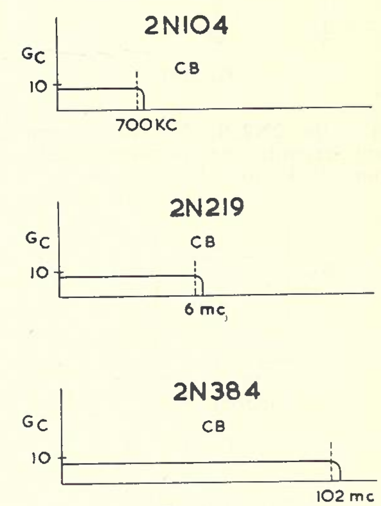


Fig. 128

Although these are impressive bandwidths, note that in each case, the current gain has dropped from beta (around 50) to alpha (less than 1). That is, going from CE operation to CB operation extends the bandwidth by a factor of beta, but at the same time reduces the current gain by the same factor.

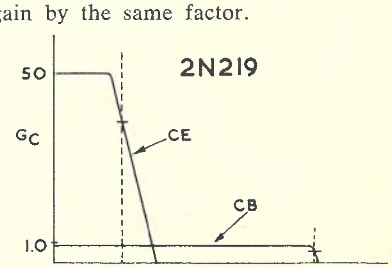


Fig. 129

In the common-base case, the frequency at which the current gain is down 70 per cent (6 mc for the 2N219) is called the *alpha cut-off frequency*, f_α. It is the frequency most commonly given in transistor data sheets, and is related to $f\beta$ by the expression:

$$f_\alpha = \beta f_\beta \qquad (130)$$

For maximum gain, it is necessary to operate a transistor in the common-emitter configuration yet this configuration gives poor frequency response. There is a need, therefore, to arrive at some configuration or circuit arrangement which will yield better frequency response without sacrificing all of the common-emitter's gain capabilities.

A simple circuit arrangement which gives better frequency response is the common-emitter amplifier driven from a voltage (low-impedance) source:

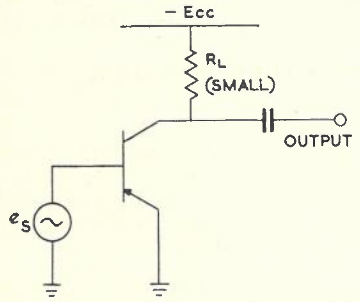


Fig. 131

For the 2N219, this circuit arrangement extends the frequency response from 120 kc to 2.9 mc.:

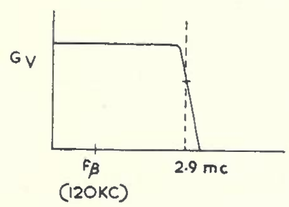


Fig. 132

At this point, it is interesting to compare this CE amplifier with a vacuum tube amplifier. We may do so easily, since the CE amplifier is a voltage amplifier, and vacuum tubes are also normally considered to be voltage amplifiers.

A typical pentode vacuum tube in the same circuit

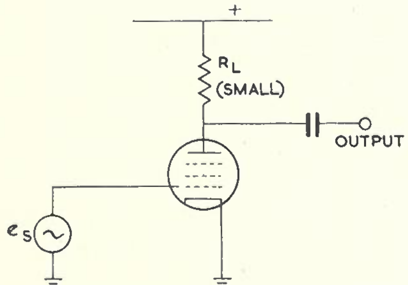


Fig. 133

would have a bandwidth several times greater than the transistor bandwidth, but its gain would be only one-half to one-third as great. It would be possible to make a tube circuit which would behave almost like a 2N219, but to do so would require a pentode with a high transconductance — more than 22,000 μmhos—and would also require the use of a low-pass filter in the grid circuit, to simulate the poor frequency response of the transistor:

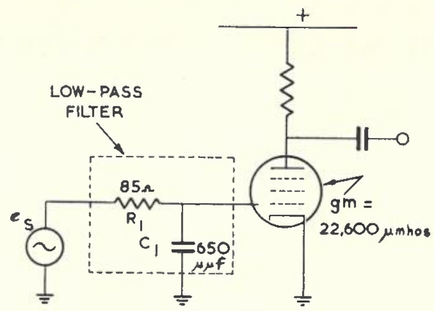


Fig. 134

The 70 per cent response point of the low-pass filter is at a frequency

$$f = \frac{1}{2\pi R_1 C_1}$$

$$= \frac{1}{2\pi(85\Omega)(650\mu\mu f)} = 2.9 \text{ mc} \quad (135)$$

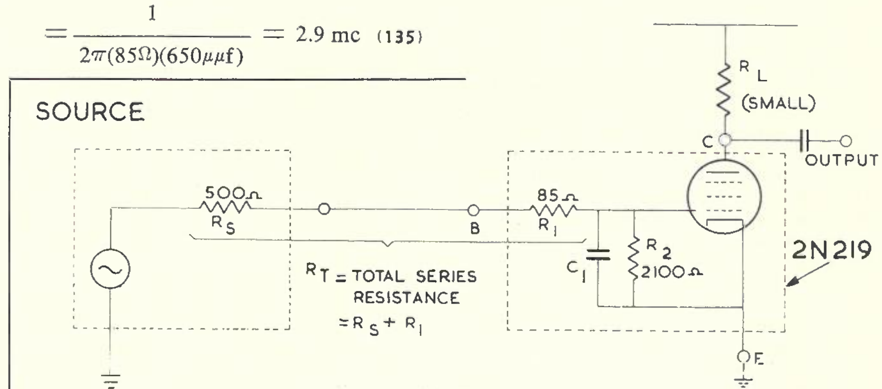


Fig. 139

which is the cut-off frequency shown in figure 132.

It is possible to extend this comparison circuit to the case of the current-driven amplifier

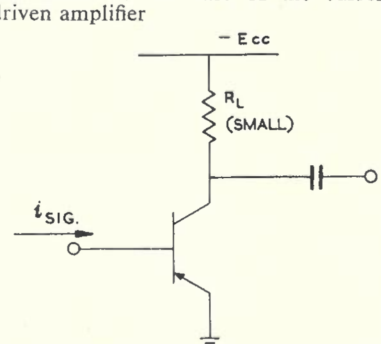


Fig. 136

merely by adding another resistor, R_2:

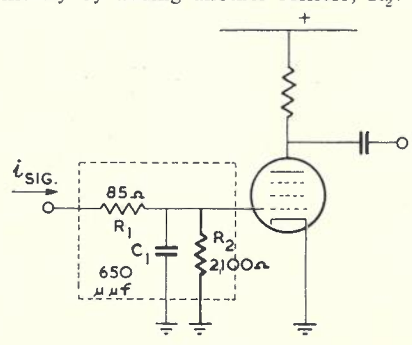


Fig. 137

In this case, the low-pass filter cuts off at

$$f_\beta = \frac{1}{2\pi R_2 C_1} \quad (138)$$

$$= \frac{1}{2\pi(2100\Omega)(650\mu\mu f)} = 120 \text{ kc}$$

which is the frequency given above as f_β for the 2N219.

In practical cases, transistors are not driven from perfect voltage sources (zero internal impedance) or from perfect current sources (infinite internal impedance), but from sources of some definite impedance. For example, a possible source for a 2N219 could have an internal impedance of 500 ohms:

In this case, it can be shown that the original f_β bandwidth is improved by a factor of 4.6:

$$f' = f_\beta \left(1 + \frac{R_2}{R_T}\right)$$

$$= 120 \text{ kc} \left(1 + \frac{2100}{500 + 85}\right) \quad (140)$$

$$= 120 \text{ kc } (4.6)$$

$$= 550 \text{ kc}$$

Another simple circuit which extends bandwidth considerably is the circuit which includes an unbypassed emitter resistor:

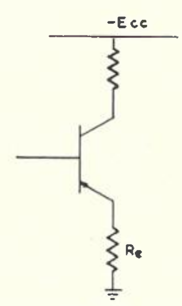


Fig. 141

In this case, the beta cut-off frequency is extended by an even larger factor, as shown in this expression:

$$f' = f_\beta \left(1 + \frac{R_2}{R_T} + g_m R_e \frac{R_2}{R_T}\right) \quad (142)$$

Note that this expression is the same as (140) above, except for the addition of one more term in the parentheses. Moreover, adding R_e in the emitter causes a "reflection" of R_e to appear in series with R_1 in the low-pass filter;

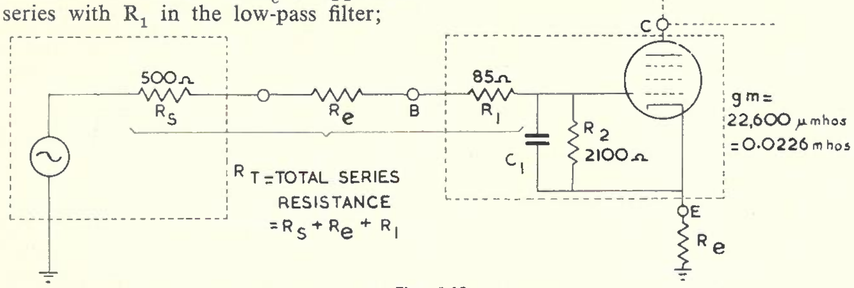


Fig. 143

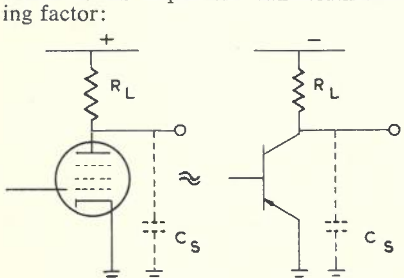
which means that a resistance equal to R_e must now be included in R_T, the total series resistance. If the value of R_e is, for example, 300 ohms, the new bandwidth is:

$$f' = 120\text{ kc}\left(1 + \frac{2100}{500 + 300 + 85} + (0.0226)(300)\frac{2100}{500 + 300 + 85}\right) \quad (144)$$

$$= 120\text{ kc}\,(1 + 2.36 + 16.0)$$

$$= 2.33\text{ mc}$$

In all the foregoing discussion, the load resistor, R_L, was clearly tagged "small", in order to avoid, temporarily, the additional complications which arise when the load resistor is not small. The first complication is familiar to anyone who has used a vacuum tube in a wide-band amplifier—stray capacity across R_L enters as an important bandwidth-limiting factor:



$$F = \frac{1}{2\pi C_s R_L}$$

Fig. 145

Just as in vacuum-tube practice, the effects of this capacity may be counteracted by an appropriate peaking network.

The other complication is also familiar to vacuum-tube users—the so-called "Miller Effect". In a vacuum tube, a small feedback capacity—typically about 2 μμf—appears between grid and plate:

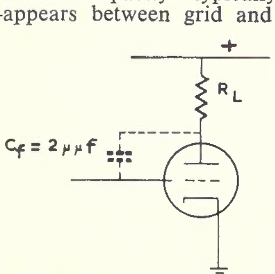


Fig. 146

If the load resistor R_L is large enough to give this tube a gain of 7, for example, the small capacity C_f is multiplied by 1 + the gain, and appears as an 8-times larger capacitor shunting the input:

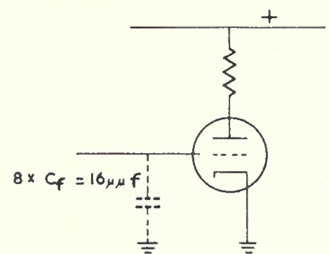


Fig. 147

In transistors, a similar effect takes place. If the load resistor is large enough to give a useful gain, then a feedback capacity C_f which appears in this manner;

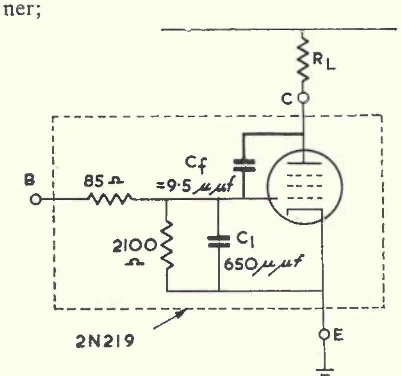
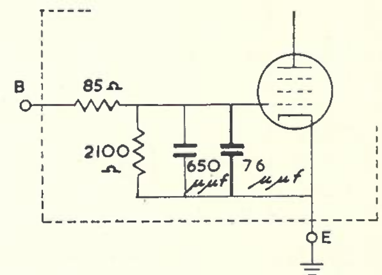


Fig. 148

is magnified by a factor 1 + the gain, and appears across C_1. If the gain is 7, for example, then the magnified capacity is

$$(1 + 7) \times 9.5\ \mu\mu f = 76.0\ \mu\mu f \quad (149)$$



which affects the transistor's bandwidth the same as would an increase of C_1 from 650 μμf to 726 μμf.

The preceding examples used the 2N219. By present-day standards, this is a transistor of moderate frequency response, designed principally to be used as the mixer in transistorized broadcast-band receivers. The examples may be converted to show the behaviour of a 2N104 or a 2N384 by substituting the appropriate values in this table:

Equivalent Circuit Parameter	*2N104*	*2N219*	*2N384*
R_1	290Ω	85Ω	50Ω
R_2	1380Ω	2100Ω	1040Ω
C_1	6900μμf	650μμf	90μμf
C_f	40μμf	9.5μμf	1.3μμf
g_m	32,000 μmhos	22,600 μmhos	56,800 μmhos

(150)

The reader is invited to make the substitutions to extend his familiarity with the frequency response of various transistors.

PULSE OPERATION

When a pulse is to be amplified, linearity is not a requirement of the amplifier. Consequently, the tube or transistor which is used as a pulse amplifier can be used as a switch, by driving it from cut-off to saturation:

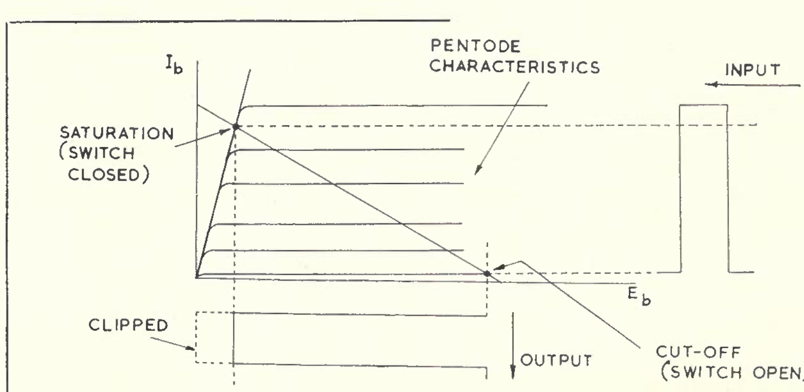


Fig. 151

The output pulse is very large under these circumstances. Its peak value is very nearly equal to the power supply voltage:

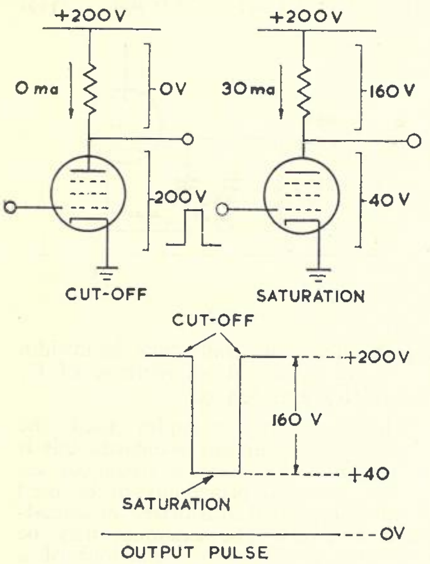


Fig. 152

Note that even in saturation, the tube still has a 40-volt drop across it. Since it draws 30 ma in this condition, the power dissipated by the tube during the pulse is

$P_p = IE = (30 \text{ ma})(40 \text{ volts}) = 1.2 \text{ watts}$ (153)

and the power switched (peak pulse power) is:

$P_s = (30 \text{ ma})(160 \text{ v}) = 4.8 \text{ watts}$ (154)

which is 4 times as large as the tube dissipation.

A transistor can be used in much the same manner, but with two major differences: the output voltage is limited to (typically) 25 volts, and the drop across the saturated transistor is typically 0.1 volt:

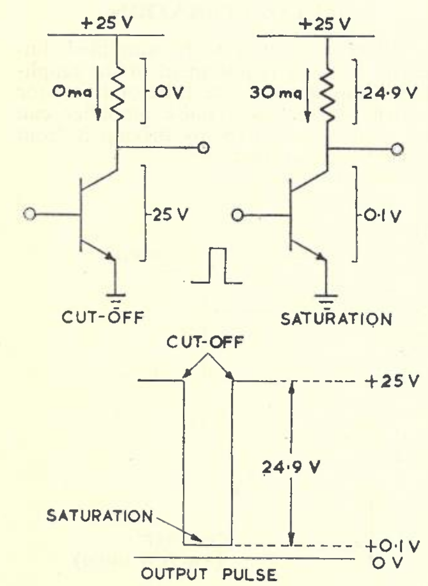


Fig. 155

In this case, the transistor dissipates (during the pulse) only

$$P_c = IE = (30 \text{ ma})\ (0.1 \text{ v}) = 3.0 \text{ milliwatt} \quad (156)$$

while the peak pulse power (power switched) is

$$P_s = IE = (30 \text{ ma})\ (24.9 \text{ v}) = 747.0 \text{ mw} \quad (157)$$

While the tube switched only 4 times as much power as it dissipated, the transistor switched 249 times as much power as it dissipated. The transistor is obviously a very efficient switching device.

The excellent switching characteristics of transistors make them very useful in such applications as driving a 4-volt pulse into a 75-ohm coaxial cable in video pulse distribution systems. In this application, the transistor behaves in the same manner as the switch in this circuit:

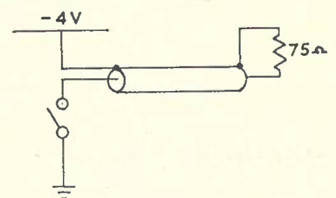


Fig. 158

Every time the switch is closed and then opened, a 4-volt pulse appears across the 75-ohm resistor. If the switch is replaced by a transistor which is driven into saturation by an input pulse,

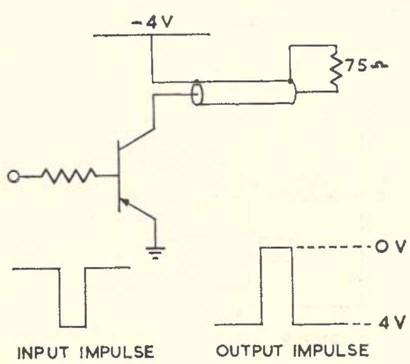


Fig. 159

the transistor will open and close like a switch, alternately disconnecting and connecting the battery and the coaxial cable, and thereby causing a pulse to appear across the 75-ohm terminating resistor.

One of the most attractive features of this circuit is that the transistor's excellent switching efficiency makes it possible to drive 4 volts into a 75-ohm line with a tiny, low-power transistor. The simple circuit shown has a number of drawbacks, such as failing to provide sending-end termination for the coaxial cable. However, this fault and others are easily remedied by more sophisticated circuitry, so circuits similar to it will no doubt find wide use in video pulse distribution systems.

Whenever a pulse is amplified — whether by tube or transistor—there is a tendency for the amplifier to degrade the pulse somewhat. In a tube amplifier, the stray capacities tend to degrade the rise and fall times of the pulse, in a manner exaggeratedly shown here:

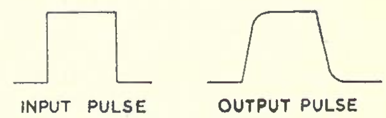


Fig. 160

In a transistor amplifier, this action is worsened by the various internal capacities of the transistor. These capacities were discussed in the preceding section of high-frequency amplifiers, although the exact values given there are not valid for large signal swings such as are commonly found in pulse amplifiers.

In a *saturated* transistor pulse amplifier, another degradation enters in the form of *pulse lengthening,* which distorts the input pulse in this manner:

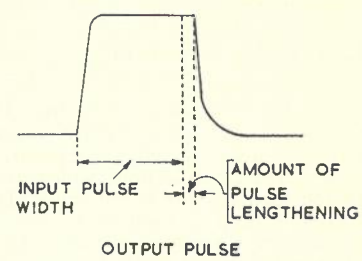


Fig. 161

The degree of lengthening depends upon how hard the transistor is saturated. If the pulse width is not critical, a fair amount of lengthening can be tolerated. However, if the input pulse must be faithfully reproduced at the output, careful engineering is needed to minimize the lengthening. The engineering problem is eased considerably by the availability of switching transistors which are constructed to minimize this effect.

TEMPERATURE EFFECTS

In the first article of this series, the transistor was introduced as an extension of a junction diode. It was shown that the reverse-biased collector junction passed a small current, just as would be expected of any junction diode:

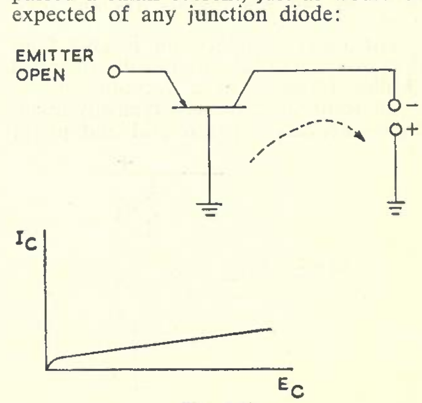


Fig. 162

This current has two components. The first component results from simple resistive leakage paths,

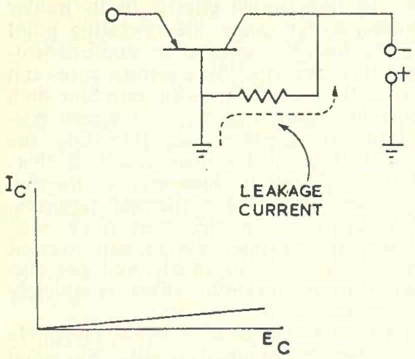


Fig. 163

and the second component, called *saturation current,* results from a semiconductor action:

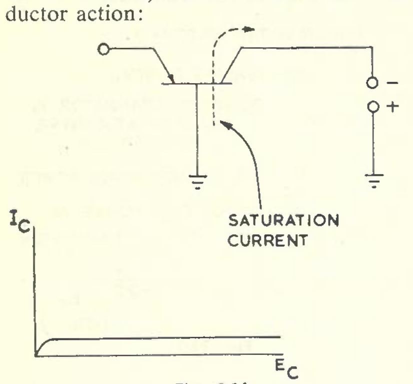


Fig. 164

Although the saturation current is little affected by changes in collector voltage, it is extremely sensitive to changes in temperature. As junction temperature is increased, the saturation current increases:

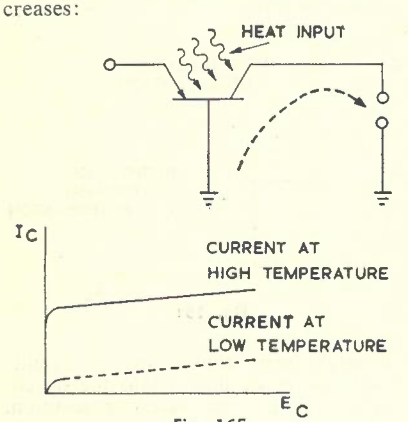


Fig. 165

The increase is very rapid; the current doubles about every 9 C. However, even at the highest operating temperatures, this relatively small current does not often cause trouble *as long as the base is grounded.*

However, the transistor is often operated with the emitter grounded. In this configuration, the tiny reverse[1] current must pass through the base-emitter junction as well as the base-collector junction,

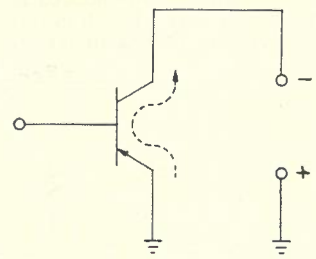


Fig. 166

and in so doing, becomes amplified by the current-amplifying mechanism of the transistor. Consequently, the reverse current for the CE configuration is beta times greater than the reverse current for the CB configuration. With this larger current being doubled for every 9 C temperature rise, the high-temperature reverse current becomes a factor deserving serious consideration.

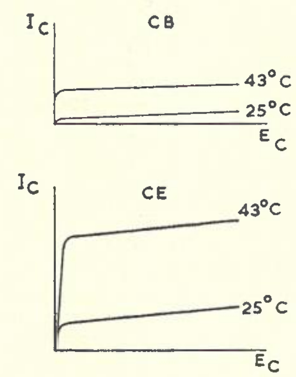


Fig. 167

The family of curves is not distorted by the high-temperature reverse current, but merely displaced, intact, to another area of the graph:

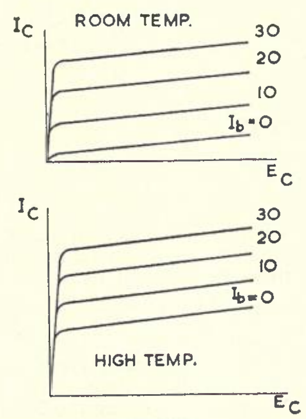


Fig. 168

This displacement can seriously disturb the functioning of an amplifier. Consider the effect that elevated temperatures would have on this simple CE amplifier:

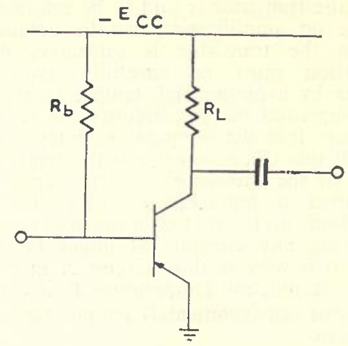


Fig. 169

At normal operating temperatures, a sine wave input gives relatively distortion-free output:

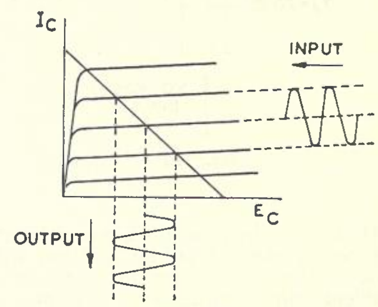


Fig. 170

If the temperature is raised, however, the curves shift upward, and the amplifier begins to clip:

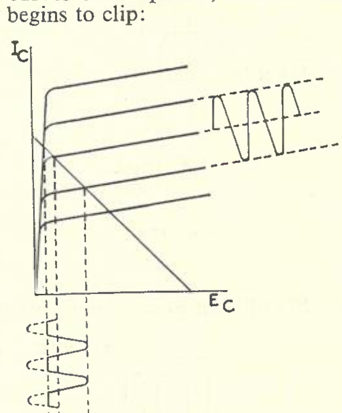


Fig. 171

At a sufficiently high temperature, the signal is completely clipped,

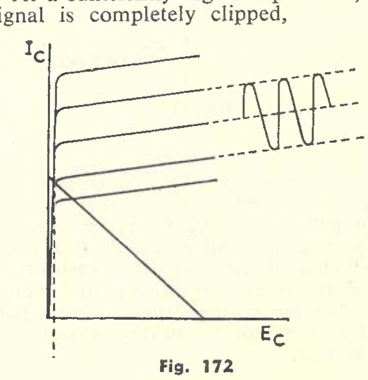


Fig. 172

(1) Since the temperature problems are tied to only the saturation component of the total reverse current, the resistive (leakage) component will be ignored in this discussion for the sake of simplification.

and the transistor is said to be saturated. Since no amplification can be obtained when the transistor is saturated, this situation must be carefully avoided, either by avoiding high temperatures, or by improved biasing circuitry, or both.

Note that the temperature referred to in all this discussion is *not* the temperature of the transistor's environment, but is rather the temperature of the collector junction itself. If the transistor is not drawing any current (as might be the case if it were in dead circuit or in storage) the junction temperature T_j and the ambient (environmental) temperature are the same:

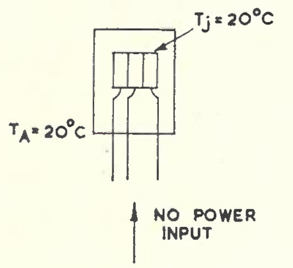


Fig. 173

However, when there is a power input, the heat dissipated at the junction will raise the junction temperature above the ambient temperature. For example, a 10-milliwatt power input might raise T_j by 5C,

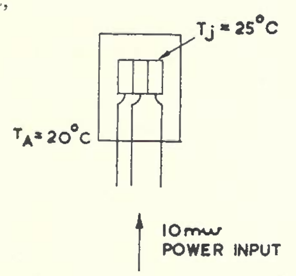


Fig. 174

and a 20-milliwatt power input, by 10C.

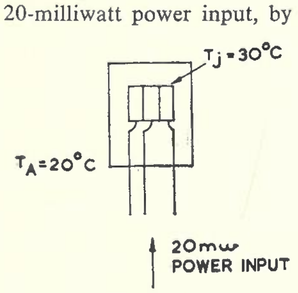


Fig. 175

It is correct to deduce from these two cases that every 1 milliwatt of power input will cause a 0.5 C rise in junction temperature for this particular transistor. This characteristic of a transistor is called its *thermal resistance,* and would be listed in the data sheet of this particular transistor as having a value of 0.5°C/mw.

The thermal resistance of a transistor is one of its more important characteristics. It enables the transistor user to compute the temperature of the junction itself, and, using this value of T_j, to compute the temperature-induced reverse current. For example, if a transistor has a reverse current of 6μa in this circuit;

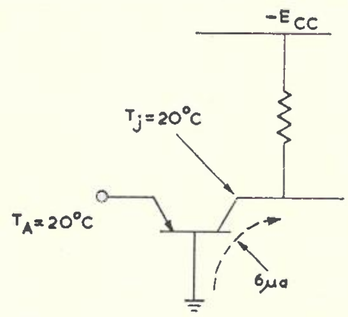


Fig. 176

it will have a reverse current of $\beta \times 6\ \mu a = 300\ \mu a$ in this circuit:

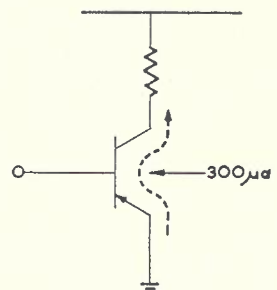


Fig. 177

If the simple single-resistor biasing technique is used (to exaggerate, for this example, the effects of temperature), and the circuit is adjusted for 54 mw dissipation,

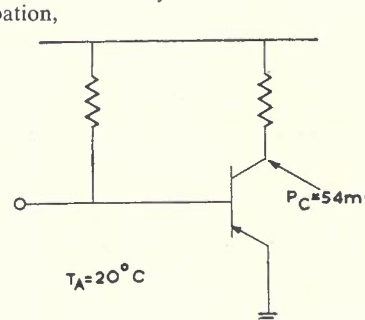


Fig. 178

then a thermal resistance of 0.5 C/mw tells us that the junction temperature is higher than the ambient by

$$0.5°C/mw \times 54\ mw = 27°C; \qquad (179)$$

and the actual T_j is 27° + 20° = 47°C. Since the reverse current doubles every 9°C, it will be eight times larger in this 27° change, causing the 300μa reverse current to become 2400 μa, or 2.4 ma.

The presence of this additional 2.4 ma could increase the dissipation to more than 54 milliwatts, thereby causing more heating of the junction, which would result in even more reverse current, thereby causing even more heating, and so on. This mechanism, which is called *thermal regeneration,* can have a number of undesirable effects. In its milder forms, it can cause the operating point to be unduly sensitive to ambient-temperature changes. More serious cases can drive the operating point into the high current region, with the consequent possibility of clipping and distorting the signal. The most serious result of thermal regeneration, however, is *thermal runaway,* which is a thermal regeneration resulting in the transistor's self-destruction. Proper design can prevent both of the serious effects, and can also make even the mild effect completely negligible.

Thermal regeneration is not inevitable in transistor circuits. It occurs only when an increase in collector current causes an increase in collector power. This is true only for operating points falling on the lower half of the load line:

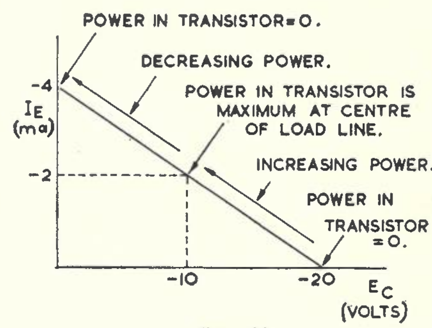


Fig. 180

When the operating point is on the lower half of the load line, an increase in current causes an increase in power; this is thermal regeneration. When the operating point is on the *upper* half of the load line, an increase in current causes a *decrease* in power; this is *thermal degeneration.*

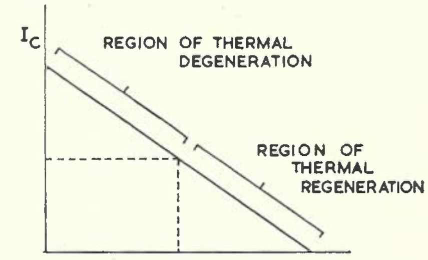


Fig. 181

It might seem that transistor circuits should always be biased into the degenerative region as a safety precaution. However, this is usually not necessary. Proper circuit techniques make the regenerative region so stable that it is commonly used, particularly since it is the low current region of the load line and therefore minimizes the current drawn by the equipment.

Maximum Power Dissipation.

The thermal resistance given in a transistor's data sheet may be used to compute the maximum power dissipation allowable at a given ambient temperature. A typical small germanium transistor usually has a maximum allowable junction temperature of 85 C. If its thermal resistance is 0.5 C/mw, and the ambient temperature is 20 C, it can tolerate only enough power to raise the junction from 20 to 85 C, a change of 65 C. Since each milliwatt contributes 0.5 C, 130 mw will give a rise of 65 C:

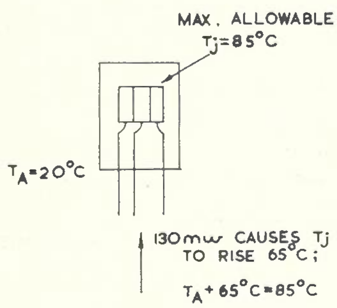


Fig. 182

At this ambient temperature, 130 mw is the maximum allowable power input. At higher ambient temperatures, the maximum allowable power input is less than 130 mw:

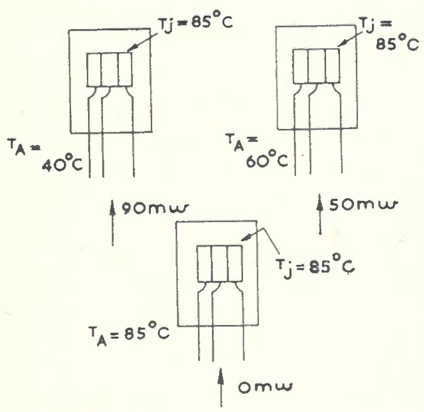


Fig. 183

or, to put it another way, if this transistor has a 50-mw power input (for example), the ambient temperature must not rise above 60 C, or the junction temperature will exceed 85 C. Moreover, at an ambient temperature of 85 C, the transistor cannot be operated at all, since it cannot tolerate any power input.

Emitter-to-Base Voltage

The reverse current is a temperature effect related to the reverse-biased collector junction. There is another temperature effect related to the forward-biased emitter junction. This junction, which at normal temperatures has a voltage drop of about 0.2 volts across it,

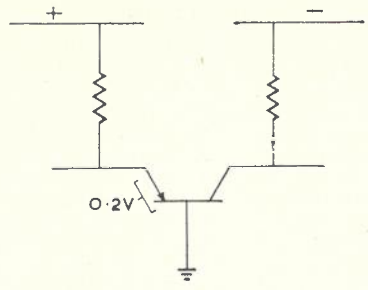


Fig. 184

at higher temperatures has a smaller drop. This effect is of no consequence when the emitter is current-biased,

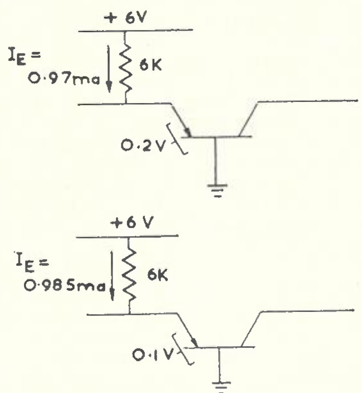


Fig. 195

but as voltage-biased conditions are approached, the bias currents can change appreciably with temperature:

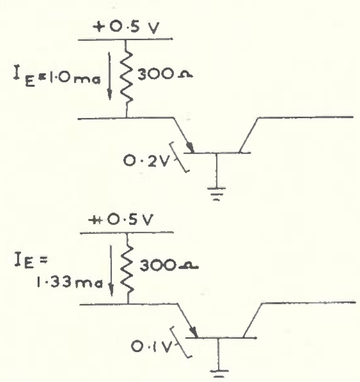


Fig. 186

In general, voltage-bias of the emitter should be avoided, unless the circuit can accommodate the changes in operating currents without giving improper operation.

Stabilizing Circuitry

The temperature dependence of transistors can be minimised by the proper circuitry. For example, the performance of the simple common-emitter can be improved by moving the biasing resistor from the power supply to the collector:

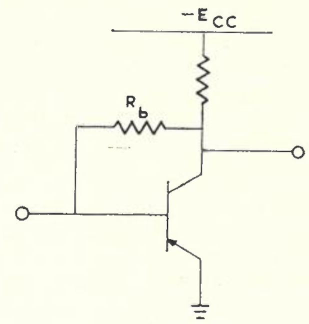


Fig. 187

In this arrangement, any increase in collector current causes the voltage at the collector to decrease, thereby decreasing the bias current flowing through R_b into the base. When base current decreases, the collector current also decreases, thereby tending to restore the original operating condition.

A transistor may also be stabilized by the use of this circuit:

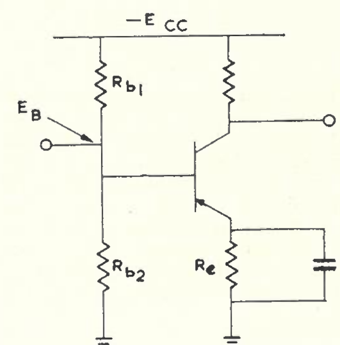


Fig. 188

Here the fundamental requirement is that the bleeder current flowing through R_{b1} and R_{b2} be so much larger than the base current that changes in base current cannot influence the voltage at the mid-point R_{b1}/R_{b2} divider. Under this circumstance, the base voltage cannot change, and the circuit behaves like a biased-up common-base amplifier, insofar as the bias currents are concerned:

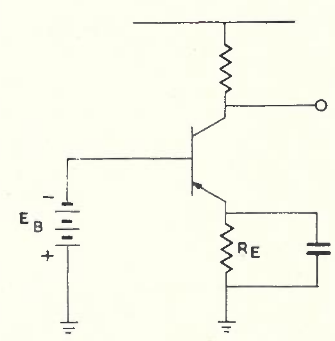


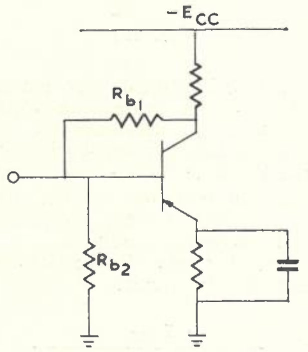
Fig. 189

The emitter current (and therefore, the collector current) is determined principally by the "battery" voltage and the emitter resistor:

$$I_E = \frac{E_B}{R_E} \quad (190)$$

(This expression assumes that the "battery" voltage is much greater than 0.2 operating point is therefore almost inde- volts across the emitter junction.) The pendent of temperature, since neither E_B nor R_E is influenced by temperature.

The two foregoing circuits are sometimes found combined in a single circuit for increased stability:



F.g. 191

The common-base amplifier with current bias exhibits the best obtainable single-stage temperature independence. However, it lacks the gain capabilities of the common-emitter configuration. Some circuits can be arranged to make use of the good features of both the CE and CB configuration. This is accomplished by making the amplifier a CE configuration for signal currents:

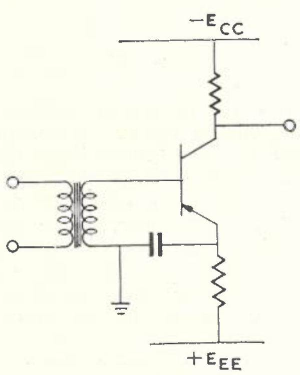


Fig. 192

and a CB configuration for bias currents:

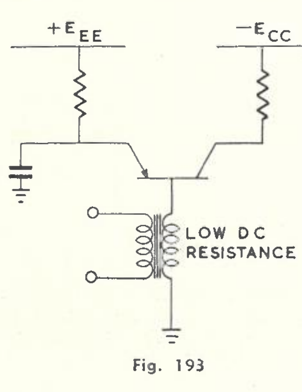


Fig. 193

CONCLUSION

The information given in this series of three articles can be considered as nothing more than a narrow introduction to a broad subject. The material in these articles, properly assimilated, will facilitate a more detailed study of transistors, using one of the many excellent texts currently available (see the bibliography at the end of this article).

The appendix which follows presents a few easily-constructed circuits to illustrate some of the principles discussed in the articles. Some of these circuits assume that the standard television pulse waveforms—sync, drive, blanking, and video—are available to the constructor. The other circuits require less elaborate facilities.

BIBLIOGRAPHY

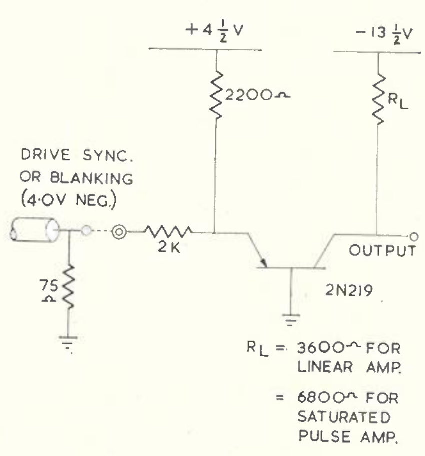
The list which follows does not include many important transistor books, but will serve to guide the reader to these and other references:

1. Lo, Endres, Zawels, Walhauer, and Cheng, *Transistor Electronics*. Prentice-Hall, 1955.
2. *Transistors I*. RCA Laboratories, 1956.
3. Riddle and Ristenbatt, *Transistor Physics and Circuits*. Prentice-Hall, 1958.
4. Hurley, *Junction Transistor Electronics*. John Wiley Sons, 1958.
5. Hunter (ed), *Handbook of Semiconductor Electronics*. McGraw-Hill, 1956.

APPENDIX

The following circuits have been designed to illustrate some of the principles of transistors. A 2N219, which is relatively inexpensive, will give very good results in any of the circuits except where noted otherwise. The potentials were chosen as those obtainable from two inexpensive batteries; the VS028 (4½ volts) and the VS304 (13½ volts).

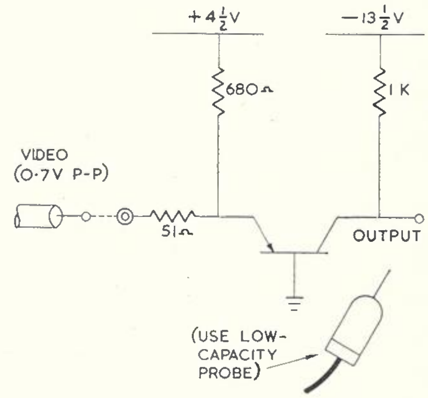
1. *A common-base amplifier*



Remarks: The 2N219 shown here can be replaced by almost any PNP transistor, although audio-type transistors (such as the 2N109) will give poorer pulse performance. To use an NPN transistor, change the −13½ volts to +13½ volts, and the +4½ volts to −4½ volts. For saturated operation with an NPN transistor, omit the 2200-ohm resistor and the 4½-volt bias supply.

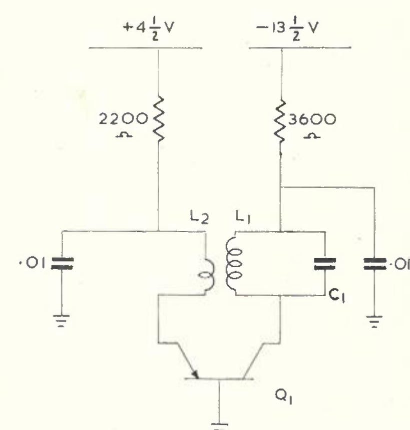
This amplifier has a gain of 1.8 as a linear amplifier (Gv = 3600/2000). As a saturated pulse-amplifier, its output is 13½ volts of pulse.

2. *A common-base -video amplifier*



Remarks: The transistor used here should have an alpha cut-off frequency somewhat greater than the desired bandwidth. As shown, a low-capacity probe should be used to view the wave-form. An NPN transistor may be used by reversing the polarity of the power supply voltages.

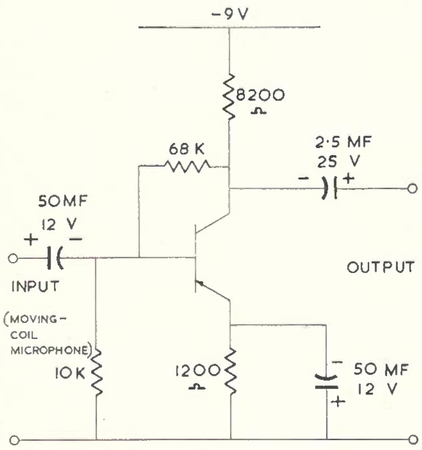
3. *A common-base oscillator*



Remarks: This simple oscillator will operate over a wide range of frequencies. For example, it will oscillate on the broadcast band if L_1 is a North Hills brown dot (105-200 mh), C_1 about 180 mmf, L_2 about 20 turns of # 26 wire wound between the pies of L_1, and Q_1 a 2N219. The circuit should oscillate to at least 12 mc with the 2N219, with appropriate changes in the resonant tank L_1-C_1 and in the feedback winding L_2. (L_2 should have about one-sixth the number of turns of L_1). With a 2N247, oscillations can be obtained to at least 60 mc, and with a 2N384, to at least 150 mc.

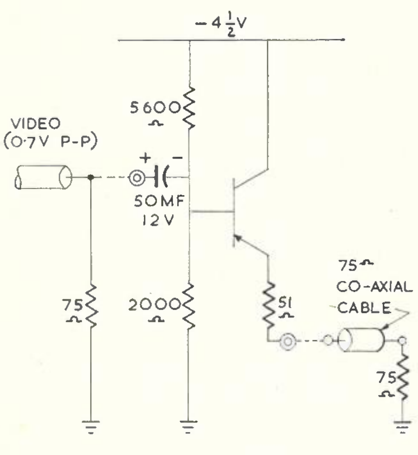
If the circuit does not oscillate, try reversing the leads from L_2.

4. *A common-emitter microphone preamplifier*[1]



Remarks: This circuit illustrates the temperature stabilization discussed in Part III. The original circuit used a 2N109, but almost any PNP transistor should perform adequately. The circuit was designed to use an RCA 239S1 2⅛" speaker as a microphone. In such operation, one of the holes in the back of the speaker should be covered with cardboard having a 1/32" hole drilled in it. The remaining holes in the back of the speaker should be covered with felt, and the speaker mounted in a baffle or case.

5. *A common-collector line driver*



Remarks: This line-driver provides proper terminations for a 75-ohm line. It has a gain of one-half. Its bandwidth can be calculated from expression (142) in Part III.

(1) Circuit and speaker-modification courtesy of RCA Semi-conductor Division, Somerville, N.J.

BOARD OF EDITORS

Mr. V. J. White has resigned from the Board of Editors following his promotion as Officer-in-Charge, Recruitment and Examinations, in the Public Service Board and his transfer to Canberra. Mr. White was responsible for a number of valuable improvements in the production of the Journal and, in addition, contributed several articles to the Journal. In recognition of his services he has been made a Life Member of the Society. Mr. D. P. Bradley, Sectional Engineer, Lines Section, Central Office, has kindly consented to replace Mr. White as an Editor of the Journal. Life Membership has also been conferred on Mr. J. W. Pollard, who has been a sub-editor of the Journal since 1944. Mr. Pollard has been responsible throughout the whole of the period for the preparation of the indexes included with each volume of the Journal as well as the six-volume indexes, the second of which will be published shortly. In addition he has been for many years, a very active agent for the Society.

TECHNICAL NEWS ITEM

TELEVISION RELAY

In planning its broadband telecommunication network between major cities, the Postmaster-General's Department has always borne in mind the possibility of requirements for television relay facilities. However, until recently, there has been no firm demand for this type of service, and (with the exception of the Sydney-Melbourne coaxial cable), equipment had not been ordered for providing television relay.

With recent Government approval for the extension of television to country areas, however, there is now a firm requirement for relaying ABC capital city programmes to most of the various country centres. The proposed country transmitters will be located in districts having the following principal cities: Townsville, Rockhampton, Toowoomba, Lismore, Newcastle, Orange, Wollongong, Canberra, Ballarat, Bendigo, Shepparton, Traralgon/Morwell and Launceston. The Department will be providing television relay facilities, co-ordinated with normal telecommunication services, from the nearest capital city to all except three of the transmitters; Townsville, Rockhampton and Launceston. Local studios will be used at Townsville and Rockhampton, and direct pick-up for Hobart transmissions will be used at Launceston, at least in the early years.

Broadband radio system equipment is being ordered to provide these services, in accordance with a programme which requires Canberra to have National television service by late 1962, other stations being provided at intervals later. In some cases radio equipment is being added to established broadband systems. For example, on the Sydney-Canberra and Melbourne-Bendigo routes telephony radio bearer circuits capable of carrying 960 trunk conversations and standby circuit are in operation. The standby circuit on such routes will be shared by the telephony circuit and future television channels. In this connection it is normal for up to 5 working bearer circuits (either telephony or television) to share the one standby to which they are switched automatically. In other cases the initial system installation including buildings, towers, antenna and radio bearer equipment and standby is required. In the event of similar television relay channels being required by commercial television stations (which are to be established in the same areas as the National stations) the Department would be able to make the necessary provision by adding extra radio bearer equipment to the existing and proposed systems.

The Department will also be establishing switching centres in Brisbane, Sydney, Canberra and Melbourne, to provide flexible interconnexion points for the exchange of intra-State and inter-State television programmes and for monitoring and testing the relay links.

RETIREMENT OF MR. A. WILSON

Mr. A. Wilson, Assistant Engineer-in-Chief, Plant, retired from the Postmaster-General's Department on the 9th February, 1961, after long and distinguished service in the Engineering Division. Details of Mr. Wilson's career were given in the June, 1959 issue of this Journal.

The Society and the Board of Editors join in wishing Mr. Wilson a long and happy retirement.

INDEX VOLUMES 7 TO 12

A comprehensive index covering the contents of volumes 7 to 12 inclusive is nearing completion. Arrangements for its distribution will be announced in the next issue of the Journal.

REVIEW OF TELEPHONE TRAFFIC ENGINEERING — PART II

*I. A. NEWSTEAD, B.Sc., B.A., D.I.C., A.M.I.E.Aust.**

Editorial Note: This article is the second and final article in a series which was commenced in the previous issue of this Journal, Vol. 12, No. 6.

LINK SYSTEMS

Link Selection

Where the outlet availability of a single switching stage is insufficient to carry the traffic efficiently, a secondary stage of selection may be added. The coupled stages can either be trunked in tandem or as a link pair. With tandem selection the primary and secondary stage outlets are selected sequentially—an example of tandem selection is the use of secondary preselectors on certain levels of 10-outlet bimotional switches. With link selection, also known as conjugate selection, a free path must be found to couple the calling inlet with an outlet of the required destination group. Link trunking is used to achieve a high traffic efficiency with small capacity selectors and is the standard method of trunking for modern crossbar systems. Link systems can consist of more than one intermediate link stage. Also the outlets of a number of link system units may be combined in a grading or interconnecting scheme.

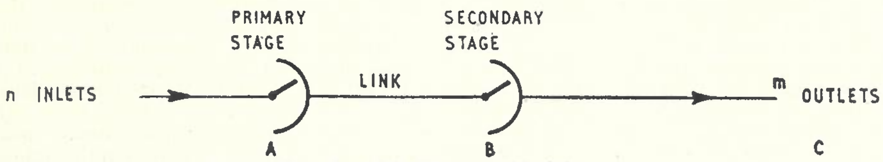


Fig. 13.—Link Selection Principle.

Link Congestion

To establish a connection from inlet to outlet it is necessary to combine a free link with a free outlet.

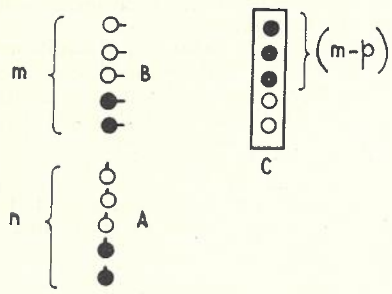


Fig. 14.—Link Selection—Crossbar Symbols.

Using the crossbar trunking symbols, the link trunking of Fig. 13 is shown in Fig. 14. In the example, two A inlets are connected through B links to outlets other than in the C group. Also there are 3 calls to C outlets from inlets other than of the A group. Further calls cannot be made between A and C, even though there are vacant A-inlets and C-outlets, as there is no suitable B link to establish the connection. This condition is known as 'link congestion' or 'internal congestion'. Thus, internal congestion occurs between particular inlet and outlet groups when there are p links busy and the remaining (m-p) cannot be used as their corresponding outlets are engaged on calls from other inlet groups. Link congestion is also known as "matching loss" in the Bell System practice.

Link congestion can be expressed in general form by:—

$$E = \sum_{p=0}^{m} G(p) \quad H(m-p) \quad \ldots\ (22)$$

where G(p) is the probability of exactly p B-links being engaged, and H(m–p) of (m–p) specific outlets being engaged (16). This assumes that G and H are independent probabilities. Strictly, H is dependent on p and should be a conditional probability $H(m-p|p)$. The practical result of assumed independence is that actual congestion levels are slightly less than those predicted by this theory.

The precise form of G and H depends on the basic assumptions made about the traffic. If an Erlang distribution is assumed:—

$$G(p) = \frac{A^p}{p!} \Big/ \sum_{y=0}^{m} \frac{A^y}{y!} \quad \ldots\ \ldots\ (23)$$

Likewise on an Erlang basis, the probability of (m–p) specific outlets being occupied out of a total of m becomes

$$H\ (m-p) = \frac{E_m(A)}{E_p(A)} \quad \ldots\ \ldots\ \ldots\ \ldots\ (24)$$

Where E_m and E_p are the usual Erlang congestion expressions.

If a 'lost calls held' assumption is made, similar results will be obtained in terms of the Poisson expressions.

If account is taken of limited sources, a binomial distribution may be assumed, (also known as the Bernoulli distribution) in which case

$$G(p) = \binom{m}{p} \alpha^p\ (1-\alpha)^{m-p} \quad \ldots\ (25)$$

where α is the mean load carried per link

and $H(m-p) = \alpha^{m-p}$ .... (26)

This is equivalent to regarding the m links themselves as the traffic sources.

Alternatively, for a number of external sources $S > m$ the Erlang-Bernoulli distribution may be used.

$$G(p) = \frac{\binom{S}{p} \beta^p}{\sum_{y=0}^{m} \binom{S}{y} \beta^y} \quad \ldots\ \ldots\ \ldots\ (27)$$

where β is the offered traffic per source.

This expression approaches the binomial distribution for $S \longrightarrow m$, and the Erlang for $S \gg m$. The Erlang-Bernoulli distribution can also be applied to the function H(m-p) but the form of the expression is rather more complicated. The choice of the distribution for G and H depends on the trunking details and traffic characteristic of the stage concerned. In calculations by the L. M. Ericsson Company for their system, the table below applies.

The use of the binomial distribution rather than the Erlang-Bernoulli for the SL outgoing stage, results from the particular transposition of the subscriber's multiple which is used in the trunking.

Concentration and Expansion in 'Link Trunking'

The examples discussed so far have applied where the number of A inlet devices was equal to the number of B-links; i.e., n = m.

When the input efficiency is low the number of B links may be reduced below the number of A devices. This is known as concentration in the B stage. Conversely with high input load efficiency, expansion in the B stage may be used by increasing the number of B devices per input column.

The expressions for G and H with either concentration or expansion in the B stage are obtained by modification of the previous results.

Other Factors in Link Trunking.

Where the trunking imposes additional or special access conditions the theory may be rendered too complex for exact

System	Distribution G	Used H
Register-finders in the 500 T. System	Erlang	Erlang
Crossbar		
Group Selector Stages	Binomial	Erlang
SL Stages outgoing	Binomial	Erlang
SL Stage incoming (4-stage system)	Binomial	Binomial
Transit Trunk stages	Binomial	Binomial

* See page 466, Vol. 12, No. 6.

analytical solution. Problems of this class include:—

(i) limited outgoing access on a delay basis.
(ii) equipment facilities for an automatic research if congestion experienced on first attempt,
(iii) partially co-operating markers operating under delay,
(iv) special discipline for the selection of links and outlets.

In these cases, approximate solutions only are possible, and extensive traffic simulation trials must be made. With the continued development in crossbar technology and the introduction of link-trunked stages in electronic exchanges, much of current traffic research is being directed toward these types of problems.

Non-Blocking Link Systems.

It is possible to design link systems to give any prescribed level of internal congestion. A special case is the non-blocking system in which there is no internal loss. This simplest realisation is obtained with a three-stage (two-link) assembly as shown in Fig. 15.

In the crossbar case, the M inlets appear over p switches with $m = \frac{M}{P}$ inlets per switch.

Similarly the N outlets appear over s switches with n = N/s outlets per switch.

From each A switch there is one trunk to each B switch, and from each B switch one trunk to each C switch.

For non-blocking it must be possible to connect the last remaining inlet of a particular switch to the last remaining outlet of a specified switch. Under the worst condition the (m–1) inlets already in use are making calls to other outlet switches, thereby engaging (m–1), B-switches. Also the (n–1) engaged outlets of the nominated outlet switch are receiving calls from other inlet switches, thus engaging a further (n–1), B-switches. Non-blocking will be given therefore if the number L, of B switches is [(m–1) + (n–1) + 1]. i.e.

$$L = (m + n - 1). \quad \text{.... ....} \quad (28)$$

This will also be the number of outlets required per A switch. Other non-blocking forms can also be used with further link stages added.

DELAY SYSTEMS

The definition of delay systems, their application and congestion specifications were discussed in Part I of this article.

Theory concerning problems of delayed service has expanded enormously over the past decade due to the great amount of attention that has been directed towards queueing problems of various types, arising in the general field of Operations Research. In telephone switching however, the practical applications still rest largely on the earlier works of Erlang, Pollazczek, and Crommelin.

The form of delay probability distributions depends on additional parameters that do not normally affect the performance in busy-signal systems. These are the Holding-time distribution, and the Queue discipline.

Erlang (3) derived the delay distribution for the case of calls with exponentially distributed holding times, an infinite queue, and service from the queue in strict order of arrival. Under these conditions the probability of a delay D exceeding a specified time t, is given by

$$P(D > t) = P\,(D > 0)\; e^{-(N-A)\frac{t}{h}} \quad (29)$$

where, A is the traffic offered to the full-availability group of N trunks.
h is the mean holding-time of calls and P(D > 0)

$$= \frac{\dfrac{A^N}{N!}\,\dfrac{N}{N-A}}{1 + A + \dfrac{A^2}{2!} + ... + \dfrac{A^N}{N!}\,\dfrac{N}{N-A}} \quad \text{.... ....} \quad (30)$$

The average delay on calls delayed is

$$\frac{h}{N-A.} \quad \text{.... ....} \quad (31)$$

and the average delay on all calls is

$$P(D > 0)\,\frac{h}{N-A} \quad \text{.... ....} \quad (31a)$$

These expressions were tabulated by E. C. Molina of the Bell System (17), and are widely used.

Erlang also studied the case where the holding-times are constant, but only for groups of up to three channels. Some years later F. Pollaczek and C. D. Crommelin (18), independently derived the general delay distribution and the latter also produced tabulations of the average delays for a range of practical values of N and h. These have recently been extended by I. Molnar of the A.E.C. Company, U.S.A. (19).

Following his original work, Pollaczek has contributed greatly to general queueing theory, and using advanced mathematical techniques, has shown that it is possible to determine delay distributions for a wide range of holding-time distributions. Little computation of results has been made however.

In 1952 R. Wilkinson (20) of the Bell System produced working curves for the case of exponential holding-times and random order of service from the queue, based on the theoretical work of J. Riordan (21). A practical approach to circuit requirement calculation for 'gating' systems is also given—this is a process by which the queue is subdivided into a number of sections. Each section is dealt with in turn but selection from each sub-queue is random.

Delay problems become highly complex when combined with limited access or where other special conditions apply —e.g. if there is an upper limit to the time that a subscriber will wait in the queue. ('Impatient Customer' case). Simulation studies are generally needed in these cases (22), theoretical studies under special conditions have so far been restricted to queues with a single server (circuit).

In switch and circuit provision the Pollaczek-Crommelin tables are normally used where it is known that the holding-times are constant, as for example a marker, or a trunk transit register. Where the holding-times are not constant it is usual to assume an exponential distribution and use either the Erlang-Molina curves if the service from the queue is ordered, or Riordan-Wilkinson if the service is random. For circuits under exclusive manual operator control and where there is no alternate routing, it has been found empirically in the Bell Companies that the average delays experienced are best described by the Pollaczek-Crommelin curves, even though the holding-times are not constant. There is however, a known clustering of holding-times around multiples of the base call-charging period.

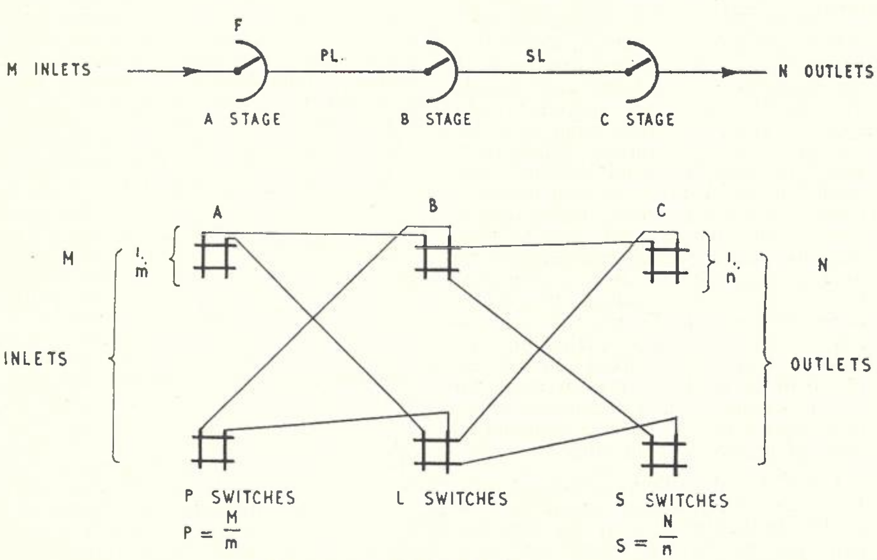


Fig. 15.—Non-Blocking Link System.

TRAFFIC MEASUREMENTS.

Traffic Measurements are made for two reasons:—

(i) To obtain traffic data for telephone planning.
(ii) To supervise the existing level of congestion.

Of measurements in class (i), the most important is traffic intensity or Erlang occupancy of circuit groups. Others include holding-times and traffic dispersion statistics. The frequency of traffic measurements for planning purposes depends on the rate of growth of the exchange or trunking, and on the length of the forward period to which plant extensions are made. This in turn may be related to the cost of the particular equipment. The faster the growth and the shorter the forward installation period, the more frequently should traffic measurements be made. Most administrations make Erlang occupancy measurements at prescribed intervals varying from 6 months to 2 years. Holding-time and traffic dispersion, being inherently more stable statistics, need to be recorded less frequently.

Measurements for congestion supervision include overflows, call-counts and occupancies of specific circuits (e.g. last choice occupancy). Full occupancy measurements can also be used if traffic recording equipment is permanently installed and its output data can be readily interpreted—that is, does not involve extensive 'processing'. Methods of congestion supervision are discussed later in this article.

Period of Measurements

The following summarises the practices amongst the countries visited:—

B.P.O. Traffic records are taken on internal equipment twice a year, usually May and November so as to include the busy season. A similar procedure applies to auto-to-auto junctions and trunks under 50 miles. Trunks over 50 miles are recorded four times per year, the philosophy being to read more often on the more expensive circuits. Readings are made on three representative (typical) days—usually Friday, Monday and Tuesday and the busiest hours for each of the days is determined for each circuit group, correct to the nearest half-hour. The busy-hour is selected by averaging the busiest hour traffic from each of the three readings without regard to time consistency.

Because of the limited capacity of the recording equipment it usually takes three to four weeks to read a complete exchange. This has several disadvantages:—

During the reading time the level of traffic will fluctuate due to the normal season trends.

It is not possible to use traffic balance checks to compare total incoming and outgoing traffic at each switching stage.

In the main trunk switching centres however, sufficient recording apparatus is provided to enable a simultaneous reading of all outgoing trunk routes.

Holland. Readings are usually taken twice per year, one set being in the busy season. The former policy was to read for only two days but the present approach is to a five day reading period. In local networks the concept of a particular busy-hour will probably be abandoned and the traffic obtained as the average of two hours reading each day (9.30-11.30 a.m.) for the five days. They consider that the average level of traffic remains fairly constant over this 2-hour period and that the additional data gained for practically no additional cost is worth more than the knowledge of a precise busy-hour traffic.

Belgium. Measurements are made annually, and if possible during the busy season. Readings extend over five days, and for each group the busiest hour of each day is established, correct to the nearest quarter hour. The traffic for each of these five busiest hours is then used to obtain an average.

On toll circuits, measurements are made during the busy-hour on the normal busiest day of each week. The result is kept in graphical form and used for determining seasonal and long-term trends.

Germany. Traffic records are taken for 4 days and the busiest hour of each day is selected, correct to the nearest quarter-hour. These are averaged to obtain present traffic. They propose, however, to change to a time consistent busy-hour approach with measurements extending over 10 days in the busy season. They believe that having established the time of the average busy hour once, they will not need to measure over all hours in future but will confine their readings to the hour previously established. The time of this busy-hour would only need to be verified about every 3 or 4 years, and would simplify the regular traffic measurements which are taken once or twice per year. As an extension of this thinking they are also examining the question of using only one busy-hour for all switching stages—the exchange busy-hour rather than the individual busy-hours of each stage.

Sweden. Traffic measurements are taken annually, as near as possible to the busy season. The reading period was recently reduced from 10 to 5 days and a common exchange busy-hour is now assumed for all circuit groups—unless there is a known divergent busy-hour for isolated special groups.

Denmark. Where automatic traffic recording equipment is installed, readings are made for 4 busy-hours each month. The four readings are spaced 6 days apart, a Monday always being included, and preferably a Saturday. These readings are used to establish the busy month, in which more detailed measurements are made. Where traffic equipment is not permanently installed, the exchange battery discharge records are used to determine the busy season. The busy week is favoured as the design period although traffic records will usually extend for a longer period in order to cover this week. A fixed hour of 9.30 to 10.30 is used for measurement for all the exchanges in Copenhagen unless it is known that there is a pronounced peak of traffic in some other hour.

U.S.A. Local traffic measurement practices vary widely between operating companies, including those of the Bell System, but in the past most companies have been taking traffic records (mainly call-counts) for two days each month and using the average of the three highest months as a design basis. The busy-hours selected are not usually time-consistent. The trend now however, is towards a time-consistent busy-hour for the ten high days during the busy season. The length of the busy season varies from two to twelve weeks depending on local conditions. The reading period will therefore be adjusted accordingly in each case to ensure that the ten high days during this season are encompassed.

On toll circuits the busiest hour of each day will probably be retained rather than a time-consistent hour, since the daily variations in the time of the busiest hour tend to be systematic, reflecting an underlying pattern in trunk call behaviour from day to day. With local traffic however, these variations are less pronounced and are mainly due to random fluctuations.

On direct trunks from which traffic may overflow to other routes, it is essential that measurements be made and traffic calculated for two separate busy-hours:—

(i) The busy-hour of the direct trunk group concerned. (Group busy-hour).

(ii) The busy-hour of the backbone route, taken as a whole. (Network busy-hour).

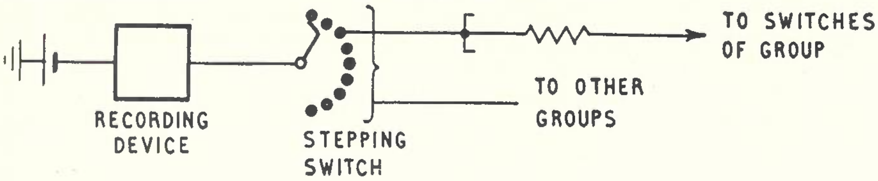
Traffic obtained from (i) is used for forecasting future offered traffic on the direct route. The number of direct circuits to be provided depends however on the network busy-hour traffic and so the future offered traffic is reduced by the factor $\frac{\text{network b-h traffic}}{\text{group b-h traffic}}$ obtained from previous measurements.

In Australia, action has recently been taken to standardise on a time-consistent busy-hour with a five day measuring period for local network traffic. On more expensive trunk circuits the reading period may be extended to ten days if this is considered warranted. In special cases where there is known to be a systematic change in the time of the busy-hour from day to day (e.g. some R.A.Xs.) the average of the busiest hour traffics may be used in preference to the normal time-consistent hour. This approach is in line with the current trends described.

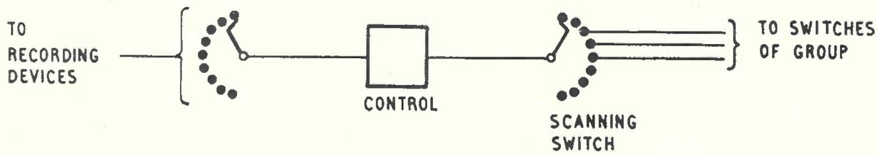
Traffic Recording Principles

Most administrations and companies have developed or are developing automatic traffic recording equipment to measure the Erlang occupancy of circuit groups by time sampling methods. This has the advantage over the earlier 'Erlang meters' (continuous ampere-hour meters) of enabling the traffics on a large number of circuit groups to be measured simultaneously. With suitable selection of the sampling interval the resulting loss in accuracy as compared to continuous recording is negligible. In sampling the occupancy of a circuit group one of two general methods may be employed:

(i) Analogue method—most commonly used is a circuit to provide a current flow proportional to the number of switches engaged.



(ii) Digital method—the circuits of a particular group are rapidly scanned in succession and the circuit is arranged to steer a pulse into summation recorders for each occupancy encountered.



With both methods, each circuit group is sampled at regular intervals. This interval should be of the same order as the mean holding time of the traffic being recorded, to ensure reasonable accuracy.

Traffic recording equipment may be portable or permanently installed. The advantage of permanent recorders is that all traffic can be measured during the busy season. Since most exchanges have their busy seasons around the same time, this is not possible with a limited amount of portable equipment. However, as a full traffic reading is normally only required annually it is most desirable that any permanent recorder be also suitable for day-to-day supervision of congestion. This will then save the cost of wiring overflow meters or other congestion supervisory aids.

Traffic Recording Equipment

U.S.A.—Bell System. The Bell System has developed standard measuring equipment known as the Traffic Usage Recorder (T.U.R.). Switches are scannd at 100 second intervals and for each selector busy, a pulse is steered to one of a bank of subscriber type registers. A 10 second scan can also be provided for measurements on short holding-time equipment. The installation has capacity for measuring on 3,600 leads. This is arranged through six 6-wire, 100 point crossbar switches. 150 registers are normally provided and the counts correspond directly to C.C.S. traffic units. An automatic camera can be installed to photograph the meters at ½ hourly intervals on 35 mm. film. The camera is mounted in a large metal masking cover which mounts over the meter plates. There are now over 1,300 T.U.R's in service and they are being installed at the rate of about 400 a year.

The T.U.R. installation at Franklin Exchange, Chicago (capacity 70,000 lines) has 26 cameras to photograph 26 x 150 traffic meters simultaneously. The equipment is used continuously, readings being taken on every traffic group for 3 days per month. These results are used for day-to-day supervision, and the 10 high days out of a year's readings are used to determine the design busy-hour traffic. At present the T.U.R's are used mainly on internal trunking with particular emphasis on the balancing of primary groups. On external circuits overflows and register call counts are used, although the T.U.R. may be extended to embrace these also. The register call counts are weighted with a holding-time figure, which is found to be fairly stable, in order to obtain telephone traffic. On routes with overflow trunking, T.U.R. occupancy measurements give no indication of the break-up amongst the various components of traffic. For this reason register call counts are preferred since each traffic component can be identified by its destination code. They are now investigating using these proportions to obtain a break-up of the total T.U.R. occupancy.

Looking further ahead, the A.T. & T. plan to completely mechanise the traffic recording activities and are designing equipment to store the traffic data from a redesigned T.U.R. directly on to magnetic tape. The magnetic tapes will be fed into an electronic computer (I.B.M. model 7070) which will summarise and extract the busy-hour traffics onto a page printer. The computer, and probably also the tape recording equipment will be centralised. Up to 30 exchanges could then feed traffic data simultaneously into centralised recording equipment. Calculations show that traffic data covering 25 days' readings, 8 hours per day, for all 30 exchanges could be stored on a single 14 inch reel of magnetic tape.

Because of their enormous quantities of common switching equipment the Bell System is prepared to invest a large amount of money in developing a fully automatic traffic recorder. They are particularly interested in the supervision of backbone routes of the national trunk switching plan, and in the balancing of line groups at the primary switching stage in local exchanges. Evidence collected shows that there is a wide disparity between the traffic levels of subscriber primary groups, resulting not only in differing standards of service, but also in inefficient use of primary switching equipment.

Along with the means for obtaining comprehensive traffic data at primary switching stages, Bell are developing new statistical methods of traffic control in order to rectify traffic unbalances detected. These are based on principles of sequential sampling whereby action control limits are established as the traffic data is accumulated. Depending on the degree of unbalance this action may vary from the non-allotment of further new lines in specific groups to the actual removal of heavily loaded lines to underloaded groups (44).

British Post Office. The standard traffic measuring equipment in the B.P.O. is the "automatic traffic recorder" which was introduced about 20 years ago (42). In recent installations the uniselector access racks have been centralised to assist fault location. It is now the policy to provide additional control switches and meters to enable a full exchange reading to be completed within about 4 weeks. Although this recorder was formerly standard equipment in the Australian Post Office, purchases have been discontinued for the following reasons: —

(i) The capital cost is high.
(ii) The wiring and jumpering is relatively complicated.
(iii) The equipment is not direct-reading —clerical work is needed to extract present busy-hour traffic figures. It is therefore not very suitable for general congestion supervision.
(iv) Because of limited capacity it is not possible to read all traffic groups at an exchange simultaneously. Traffic readings must extend over 3 or 4 weeks at least, during which time the traffic intensity will undergo seasonal changes.
(v) The fault liability has been found to be high.

Netherlands. The P.T.T. in collaboration with Philips, have developed a traffic recorder to replace the Erlang (ampere hours) meters previously used. This is based on the scanning principle, using both analogue and digital methods. The principle of operation is outlined in Fig. 16.

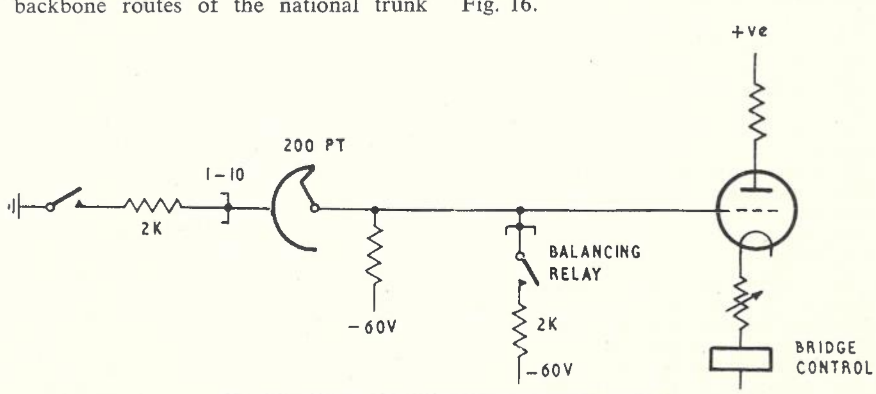


Fig. 16.—Traffic Recorder—Principle of Operation.

Contacts of an access uniselector are scanned in succession but up to 10 circuits can be connected per access-switch contact. These connections are made through 2000 ohm resistors, and an automatic bridge balancing circuit with successive relay closures is used to determine the actual number of simultaneous busy switches out of each group of 10. The count summation is recorded on subscriber type registers. The apparatus can be operated remotely and the stepping can be arranged so that either all 10 resistors relays must operate before the next step, or else stepping can be provided immediately traffic balance has been reached. This latter procedure permits faster operation, but the time difference between successive scans will vary by a small amount.

Both Belgium and France are also developing similar types of scan traffic measuring equipment.

Germany. Present traffic recording is with Erlang meters which are provided in various numbers depending on the exchange size, e.g.

1-2 thousand lines 4 meters
2-5 thousand lines 6 meters

Measurements are made throughout the year and a seasonal correction, based on the exchange battery discharge readings, is applied to traffic measured outside the busy season.

The Erlang meters are usually read by local staff but they can be arranged to impulse to a remote centre where summation and printing is made automatically.

For the large exchanges they now plan to use a scanning technique and they are developing new traffic recording equipment in collaboration with Siemens & Halske. Siemens & Halske have also developed a call dispersion recorder which samples calls on 24, 1st-selector equivalents. The equipment can analyse all two digit call-combinations and selected 3-figure codes, recording the information on subscriber type registers.

Sweden, Denmark. The Swedish Board and the L. M. Ericsson Company have developed traffic measuring equipment based on the scan principle but up to 30 circuits can be connected to each point of the crossbar access switches. These connections are made through 9,600 ohm wire-wound resistors of 1% accuracy, and pulses are steered into subscriber type registers by means of a self-balancing bridge. The equipment has a capacity for 40 measuring groups of up to 30 circuits each in the permanently installed version, or 20 circuits per group in the portable equipment. The scan interval is 36 seconds for traffic with normal holding-times, or 3.6 seconds for registers and other short holding-time equipment.

The traffic recording equipment described is provided on a basis of one unit per 10,000 lines. It is also used for congestion supervision, reading for one hour on each circuit group.

In the remaining demi-automatic exchanges in Copenhagen, traffic on the outgoing junction groups is determined by means of last-choice occupancy measurements (23), using the relation—

$$A_n = A(E_{n-1} - E_n) \quad \ldots\ldots\ldots\ldots \quad (32)$$

where, A is the traffic offered to the grading.

A_n is traffic carried by the last trunk.

E_{n-1}, E_n are the Erlang loss expressions.

Australian Requirements. The present standard traffic recorder, known as the Resistor Recorder, is based on the current flow method discussed, and is available as either a portable unit or a permanent installation (43). The need for readily obtainable and accurate traffic data, both for planning and supervisory needs, will rapidly increase as our automatic network develops. The recent decision to adopt crossbar as the future switching standard will result in greatly improved system facilities and system economies, but demands a revised and intensified approach to traffic engineering. The introduction of Subscriber Trunk Dialling also poses problems of traffic measurements on alternate routing networks. In particular, experience has shown the need to measure traffic more or less continuously on final routes where the proportion of overflow traffic is high.

In developing traffic measuring equipment to meet these future needs, the principle must be towards an increasing automation of all traffic recording and processing work, and equipment is now being developed to record automatically, traffic flow data on punched tape which will be processed by an electronic computer.

ACCURACY OF MEASUREMENTS

There are two classes of error associated with traffic measurements:—

(i) Error in estimating the carried load during the measurement period.
(ii) Error in estimating the underlying average source load.

In class (i) are included recording equipment errors, human errors and sampling errors. The sampling error is due to the undetected changes in occupancy between successive scans. The second type of error (ii), is due to the fact that the actual load presented during the measurement period is itself only a sample from the many loads that might be offered by the same source of traffic under statistically identical conditions.

L. von Sydow (24), has analysed the error with continuously recording Erlang meters, due to the manufacturing tolerances of the resistors. His analysis however is restricted to the case of random selection of outlets. With homing switches the theory would need modification to account for the prescribed order of selection, and with gradings an exact analysis would become inordinately difficult. In practice however the order of selection means that, providing care is taken to ensure that the resistors assigned to the early choices are fairly accurate, (say ± 1%) the tolerances on the remainder become less important than with random selection.

W. Hayward (25), has studied the sampling errors of both (i) and (ii) classes with the assumptions that each occupancy count itself is accurate, and that the traffic is in statistical equilibrium. He showed that, for a given scan frequency, the standard deviation of the error expressed in percent of carried load is approximately proportional to

$$\sqrt{\frac{h}{ANT}} \quad \text{where}$$

h is the average call holding-time
A is the traffic carried,
T is the length of the observation period, and
N is the number of observation periods.

These results are used by the Bell System in determining the scan interval and length of traffic measurement period. The departures from statistical equilibrium within the busy hour do not usually affect the accuracy of the carried traffic measurement significantly, since the traffic intensity passes through a maximum value and the variations tend to be compensatory. Their affect on the estimation of source load is also slight. The day-to-day variations in average traffic intensity however, can have a marked effect on the accuracy of source load estimates. It is important to include in the measurement at least one day of each of the classes of days whose characteristics differ.

In alternate routing networks, the effect of daily variations in the traffics offered to direct routes can cause large fluctuations on the final or backbone routes if the proportion of overflow/total traffic on these routes is high. This is equivalent to an unstable source load on the final route and measurements must be made over a much longer period. In fact it may be necessary to supervise some routes more or less continuously. These questions are being studied in the Bell System (12), and also by a C.C.I.T.T. sub-committee for the case of International circuits. The work of the Bell laboratories has shown that the individual overflow distributions are fitted by a Gamma (Pearson Type 3) distribution. This can be used to test whether the 10 high days are "representative" or whether some should be rejected as being abnormal in respect of a busy season population of 60. The form of the resultant distribution when several overflow traffics are compounded depends on the degree of correlation which exists between the individual distributions. A two-term Gram-Charlier distribution has been found to give a reasonable fit in the practical studies made and investigations are proceeding.

SUPERVISION OF CONGESTION

The extent of local congestion supervision required will depend on the stability of the exchange and on the frequency with which the full traffic measurements are made. Most administrations make simple sampling checks more or less continuously. These may be by means of overflow readings, call-counts, all-trunk-busy recorders, etc. In addition, test calls may be made either manually, or with automatic calling equipment.

In the B.P.O. atempts are being made to devise more reliable congestion supervision methods using overflows. In experiments at one exchange, the number of switches in final selector groups was progressively reduced while traffic was being measured and overflows taken. They found that there was some correlation between traffic and overflows, but beyond a certain point the results were difficult to interpret due to the build up of the repeated attempts. They plan to produce control charts on which the summated weekly overflows would be recorded and compared against control levels for the working mean, maximum and minimum summations. Trunking would not be reduced on less than 1 year's evidence, but action would be taken to increase the number of outlets where the overflows consistently exceeded the maximum—that is for more than 2 or 3 weeks in succession. They hope eventually to be able to extend the interval between full traffic measurements to four or five years by this type of supervision.

Although the principle of traffic control by overflows has always been most attractive, the experience of administrations over a number of years has shown that there are many difficulties in practice:—

(i) For normal grades of service the number of overflows which should be expected is of a very low order and its standard deviation is relatively very high. Thus results must therefore be examined over a considerable period before any reliable interpretation can be given. In practice this period is so long that seasonal variations tend to mask the picture.

(ii) If a grading is over-provided, overflows give no information to the extent of this over-provision. Action must therefore take the form of successive reductions by small amounts of the number of outlets until the satisfactory level is achieved. This is tedious and introduces additional administrative complexities.

(iii) Overflows can be very misleading under conditions of traffic unbalance. E.g., an excessive number of overflows may be interpreted as under-provision and the grading outlets increased, whereas a redistribution of existing trunks or a rebalancing of the input traffic is really called for.

(iv) As congestion increases it is very difficult to account for the effect of repeated-attempt calls.

The opinion of most traffic engineers is that overflow readings only provide a qualitative measure of congestion and it is not considered feasible to control equipment provision over long periods by means of overflow alone. In most Euopean administrations regular overflow readings are taken and compared against critical control levels. If these are exceeded then traffic measurements are made.

Bell System. Similarly in the Bell System, overflow meters are used in most crossbar and some step by step exchanges to provide a qualitative indication of congestion. Traffic measurements are taken before any change in the number of circuit or trunking is made. Bell Laboratories are endeavouring to develop a more reliable basis for the interpretation of overflow readings by studying the variance of the overflows as a function of the duration of the congestion periods. With Western Electric bimotional equipment there is no 11th step contact, and last-choice traffic is used for congestion supervision. On the No. 5 crossbar equipment, matching loss is supervised by a meter associated with the marker which scores whenever there is a failure to provide an internal link between calling and destination circuits. Separate meters give an estimate of matching loss for both originating and incoming traffic.

In addition to these supervisory traffic measurements, service tests are made to assess the overall performance of the system. They are:—

(i) **Dial tone speed.** 1000 test calls per hour are made using automatic equipment to measure the percentage for which the dial-tone delay exceeds 3 seconds. These test calls will affect marker occupancy but will have little effect on register traffic due to their very short holding-time.

(ii) **Matching Loss in Crossbar Offices.** Simultaneous measurements of incoming traffic and lost calls are made and evaluated against load service curves to estimate matching loss.

(iii) **Grade of Service.** Service observations are used to sample the percentage of overflow busies encountered.

Looking ahead, the installation of equipment to provide full automation of regular traffic measurements and traffic processing work will largely obviate the need for overflow meters and other traffic supervisory devices as complete occupancy readings could be readily made at a very low cost.

TRAFFIC FORECASTING

There are broadly three types of forecast associated with traffic engineering work. They are:

(1) Subscriber development.
(2) Traffic (Erlang occupancy).
(3) General traffic statistics.

Subscriber Forecasts.

It is a common experience in forecasting telephone development that, although the short-term forecasts may be high, the long-term forecasts have usually been too low. This is partly due to an insufficient allowance being made for increasing telephone density in attempting to forecast the future subscribers directly. A better approach is to make separate forecasts of population and telephone density.

The stratification of subscribers into classes indicative of their calling rates is also essential for accuracy in the subsequent traffic forecasting. A suggested classification, and the approximate range of the mean busy-hour originating rates (Erlang per line) is:—

Residential Services

	Originating Rates	
Low	.015 – .025	Rural
Medium	.025– .035	Metro-
High	.035 – .045	politan

Business Services

Single Line Services	Low	.050 – .070
	High	.070 – .090
P.B.X. Groups Size of Groups	2- 5 lines	.090 – .120
	5-10 lines	.110 – .200
	10 lines	.200 – .500

Investigation would also be required to determine which factors (property value estimates, etc.) correlate best with traffic calling rates and how this classification could be made.

Traffic Forecasts

The general problem is to predict the traffic in Erlangs on a route at a prescribed future period when the traffic at some base period is known. Strictly, this problem should take into account the entire traffic dispersion of the network, although practical methods for restricted forecasting can be devised.

Ideal Traffic Dispersion. If the interest pattern amongst subs were uniform over the network, the originating traffic of any particular exchange would be distributed amongst all exchanges in proportion to the total terminating traffic of each. This can be termed the 'ideal' dispersion. Consider such a network of n exchanges. Let the total originating traffic of each be

$A_1, A_2, \ldots\ldots An$ and the total terminating traffics

$T_1, T_2 \quad . \quad Tn$

With an ideal dispersion, the traffic between exchanges i and j is given by

$$\underset{\sim}{a}_{ij} = \frac{A_i T_j}{\sum_{x=1}^{n} T_x} \qquad \ldots\ldots\ldots (33)$$

The values of the various A's and T's are obtained by multiplying the appropriate number of originating or terminating subscribers by their respective originating and terminating traffic rates—mean busy-hour erlang/line. The future subscribers are obtained from the separate forecasts referred to, and the subscriber calling rates (originating and terminating) are estimated from past records and any other known data.

The ideal-dispersion method takes no account of the varying interest pattern and is only of use in the absence of any other information. Where base-period traffic measurements are known, an elementary method of forecasting is to preserve the existing proportionate break-up by applying the observed percentage dispersions to the future originating traffic. That is

$$a^*_{ij} = \frac{a_{ij} A^*_i}{\sum_{x=1}^{n} a_{ix}} = \frac{a_{ij} A^*_i}{A_i} \qquad (34)$$

where the starred terms denote forecast values and the unstarred terms are known. Since this method takes no account of the growth of the terminating exchanges it will only be correct if the network grows uniformly, and also if the interest pattern over the network remains unchanged.

The forecast may be improved by the introduction of factors representing the community of interest between groups of subscribers. Such a factor can be defined in various ways. One definition, called a Community Factor by Kruitof (26), and a Quality Factor by Cohen and de Kroes (27), is given by the ratio of the observed traffic, a_{ij} to the ideal-dispersion traffic $\underset{\sim}{a}_{ij}$ for the particular route, that is

$$q_{ij} = \frac{a_{ij}}{\tilde{a}_{ij}} = \frac{a_{ij} \sum_{x=1}^{n} T_x}{A_i \; T_j} \quad \text{.... .... (35)}$$

The forecast traffic a_{ij}^* is given by the relation

$$a^*_{ij} = q_{ij}\tilde{a}^*_{ij} = \frac{q_{ij} A^*_i T^*_j}{\sum_{x=1}^{n} T_x^*} \quad \text{.... .... (36)}$$

q_{ij} is normally considered constant but could be modified by any observed long-term trend, and the ideal traffic $\tilde{a}^*_{ij}$ can be calculated for the future network.

When the traffic on all the routes of the network (including local/local) have been forecast they are assembled in an nxn matrix.

From exchange		1	2	....	n	Originating traffic
	1	a_{11}^*	a_{12}^*	....	a_{1n}^*	A_1^*
	2	a_{21}^*	a_{22}^*	....	a_{2n}^*	A_2^*
	n	a_{n1}^*	a_{n2}^*	....	a_{nn}^*	A_n^*
Terminating traffic		T_1^*	T_2^*	....	T_n^*	

The sums of the outgoing component traffics (horizontal lines) are then compared with the forecast total originating traffic for that exchange (right hand column). Similarly, the terminating components are summed vertically and compared with the forecast totals. In general, the matrix will not remain balanced and various methods are used to correct the distortion. The usual procedure is to assume that A*'s and T*'s are correct and use an iterative procedure scaling terms first horizontally so that

$$\sum_{x=1}^{n} a_{ix}^* = A_i^*$$

and then vertically so that

$$\sum_{y=1}^{n} a_{yj} = T_j^*$$

In practice the convergence is fairly rapid. It is possible to introduce different types of interest factors into the basic forecasting process in order to minimise the initial balance distortion of the matrix. The procedure becomes very complicated, however, and it is doubtful if further refinement is justified. There have been attempts to assign numerical values to the interest factors on the basis of the separation distance between exchanges (28). Although useful in the absence of any other data, the values found in practice can differ widely from any postulated set of values.

The practical objection to these methods of forecasting is that in order to project the traffic on any particular route it is necessary also to forecast the traffics in all other parts of the network. When the network consists of more than a few exchanges, this is a sizeable task which prevents the technique from being used very much, except for large scale network forecasting which might be undertaken, say, annually. Some administrations are developing forecasting programmes for use with high speed electronic computers, in which case a balancing procedure presents no great problem. Current forecasts of trunk line development in the Bell System are being made by an electronic computer as a trial, as well as by normal manual calculation methods. The results, and the relative effort involved will be compared and if satisfactory, future annual forecasting will be made exclusively by means of the computer.

Growth Factors. Some administrations, including a number of the Bell System companies use a modified form of forecasting based on the use of growth factors.

From equations (35) and (36)

$$a_{ij}^* = \frac{A_i^*}{A_i} \; \frac{T_j^*}{T_j} \; \frac{\sum_1^n T_x a_{ij}}{\sum_1^n T_x^*} \quad (37)$$

This can be written in the form—

$$a_{ij}^* = \frac{G_i \; G_j}{G_N} \; a_{ij} \quad \text{.... (38)}$$

where G_i, G_j, G_N are the growth factors (the ratios of future to present total traffics) for the originating exchange, terminating exchange and network respectively. This assumes that for any exchange the same growth factor applies for its originating and terminating traffic. In this form the community of interest factor does not appear explicitly but is inherent in the base traffic a_{ij} and is assumed to remain constant over the forecast period. Further simplification can be made by using the ratio of future/present subscribers as the growth factor in each case. This of course assumes that the average calling rates remain constant.

When the exchanges belong to separate areas which are growing at significantly different rates, weighted area growth factors are used. This applies also to most trunk forecasting. If the two areas are x and y then the weighted area growth factor G_x' for area x is calculated by weighting the normal growth factors G_x and G_y by the percentages of area x originating traffic which terminate in x and y areas respectively.

$$G_x' = G_x \frac{a_{xx}}{A_x} + B \frac{a_{xy}}{A_x} \quad \text{.... .... (39)}$$

Similarly .... (39)

$$G_y' = G_y \frac{a_{yy}}{A_y} + G_x \frac{a_{yx}}{A_y}$$

The new 'network' growth factor is then given by—

$$G_N' = \sqrt{G_x' \; G_y'} \quad \text{.... .... (39a)}$$

so that the forecasting formula (38) becomes

$$a_{ij}^* = \frac{G_i \; G_j}{\sqrt{G_x' \; G_y'}} . a_{ij} \quad \text{.... (40)}$$

This method is used when the weighted and unweighted area growth factors differ by more than 5%. Use of weighted growth factors reduces the balance distortion which occurs when the exchanges or areas of the network are expanding at appreciably different rates.

For comparison, the standard forecasting method used in Australia is

$$a_{ij}^* = G_{ij} \; a_{ij}$$

where G_{ij} is a composite growth factor defined by

$$G_{ij} = \frac{S_j G_i + S_i G_j}{S_i + S_j} \quad \text{.... .... (41)}$$

where S_i, S_j are the mean subscribers, over the forecast period, at i and j respectively.

This takes into account the varying rates of growth of the two exchanges or areas i and j but not the rate of growth of the total network.

GENERAL TRAFFIC STATISTICS

In addition to subscriber development and traffic occupancy forecasts there is a range of other traffic statistics which may be recorded and for which future predictions may be made. These include certain types of traffic aggregates (e.g. total trunk calls per annum), holding-times, and traffic dispersion percentages.

If the aggregates are essentially population-based they may be termed 'non-saturable' and will normally be confined within upper and lower bounds given by exponential and linear development curves. Other statistics including telephone density and calling rates (for a fixed group of subscribers) tend to approach an asymptotic limit and may be termed 'saturable'. Various equations have been used to describe the growth of these statistics, including the Plessing logistic and Gompertz curves. In the forecasting of both saturable and non-saturable traffic statistics, considerable use is made of past records in assessing the likely future trends. In some administrations (e.g. Germany and Sweden) graphical methods are also used exclusively for traffic forecasting. It is considered, however, that the best results in traffic forecasts will be obtained through the use of appropriate growth factor formulae, modified where necessary by the effect of observed trends.

Holding-time Forecasts. Holding-times remain fairly constant while the service environment remains unchanged. Conversion from manual to subscriber controlled operation has an effect, but of greater importance is a change in the base charging interval. Overseas experience has shown that the number of trunk calls usually increases by around 100% after conversion to sub-dialling. At the same time there is a reduction in the average holding-time. When the conversion is accompanied by the introduction of time-zone metering (so that unit charges are applied at shorter intervals instead of a multiple charge at 3 minute intervals) the reduction in holding-time is significant, since subscribers are effectively only paying for the time they use the circuit. The corresponding increase in traffic may then only be around 25%, even though the number of calls has doubled. If however the charges are continued to be applied at the former three minute intervals, there is not the same incentive to subscribers to reduce the length of their conversation.

SIMPLE ALTERNATE ROUTING SYSTEMS

Principle of Alternate Routing

Because of the stochastic nature of telephone traffic it is fundamental that the traffic efficiency (traffic per trunk for a fixed probability of congestion) of a circuit group will increase with the size of the group. The general form of this relationship is indicated in Fig. 17.

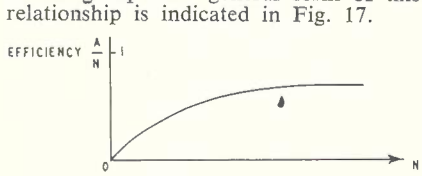


Fig. 17.—Traffic Efficiency of Circuit Group.

In disposing of the traffic of a network, maximum efficiency is therefore obtained by keeping the traffic groups as large as possible. In practice this can be achieved through tandem switching; a simple illustration of which is given in Fig. 18.

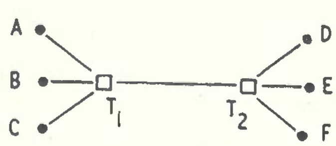


Fig. 18.—Tandem Connection of Exchanges.

Access between any of the 6 terminal exchanges shown is obtained through one or both tandem centres T_1 and T_2.

Alternatively, if all connections between exchanges were by direct routes, much of the switching equipment at the tandem centres would be eliminated. Moreover there would be a reduction in the average length of circuit. This is illustrated in Fig. 19.

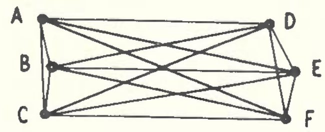


Fig. 19.—Direct Connection of Exchanges.

A further point is that for each route the transmission requirement for all calls is determined solely by two specified exchanges whereas in the tandem trunking of Fig. 19 each route must be designed to cater for the most distant calls which traverse it. However, for a network of n exchanges the average traffic load per route would be proportional to $\frac{1}{n^2}$ and so the traffic efficiency falls away rapidly as the number of exchanges increases.

The total network costs will be reduced by the economic use of both direct and tandem trunking, some traffic groups being handled on direct routes, and others amalgamated through tandem switching. *Minimum* network costs however are achieved when this principle of joint trunking is also applied to the disposal of an individual traffic group. This becomes Alternate Routing—the traffic is offered initially to direct circuits and the overflow is trunked as part of a tandem group. This is illustrated in Figs. 20 and 21. The principle can be extended with additional tandems.

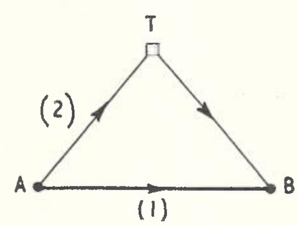


Fig. 20.—Alternate Routing Principle—one Tandem.

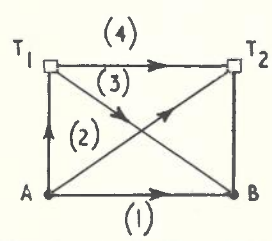


Fig. 21.—Alternate Routing Principle—Two Tandems.

The direct routes from which the traffic may overflow are termed "high usage routes". The final or 'backbone' routes are engineered at prescribed congestion levels, while the congestion on other routes will be determined in each case by the number of circuits provided to achieve the optimum economic disposal of the traffic.

Calculations of Direct Route Circuits

The condition for minimum cost is achieved when the cost of carrying a small increment of traffic is the same for both the direct and the alternate path. Under this condition

$$O_d \, K_a = U_a \, K_d \quad \text{.... ....} \quad (42)$$

where O_d is the Marginal Occupancy on the direct route; this is the additional traffic carried for the same traffic offered, when one additional circuit is added to the direct route. U_a is the Marginal Efficiency of the alternate route. This is the additional traffic that can be carried, at the same grade of service, when one additional circuit is added to the alternate route.

K_d and K_a are the respective marginal circuit costs.

With full-availability trunking on the direct route, and Erlang theory we have

$$O_d = A \, [E_N(A) - E_{N+1}(A)] \quad (43)$$

where A is the traffic offered to the direct route and $E_N(A)$, $E_{N+1}(A)$ are the Erlang loss functions for N and N + 1 circuits.

The function O_d is tabulated in the publication "Moe's Principle" by A. Jensen (1) Table IV.

Since the alternate route is usually large, the marginal traffic efficiency may be taken as constant.

Equations (42) and (43) enables the number of direct circuits N to be calculated if the marginal cost ratio and marginal traffic efficiency of the final route are known.

There is some difficulty in the philosophy to be adopted in determining marginal circuit costs. Circuits are rarely provided singly, so that when a cable is full, or all channels of a carrier system have been allotted, the true marginal cost of the next circuit is very large. This renders the M–c function discontinuous. Moreover the channel costs themselves vary with the particular type of equipment used and the time at which it is installed.

In planning on a network scale these affects will tend to average out and the Bell System adopt the principle of using *average marginal* circuit costs on all calculations wherever the route is established or has been "proved-in" economically. In particular cases where the direct group may not yet exist, a closer economic study is made.

Nature of Overflow Traffic

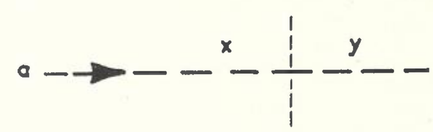


Fig. 22.—First Choice and Alternate Choice Circuits.

If Poisson input traffic of mean value 'a' is offered to a group of (x + y) trunks in sequence, the traffic offered to the y sub-section will no longer be pure-chance, but will be of more 'peaked' character due to its sporadic occurrence. This means that the Erlang solution, or other approaches based on random call arrival, is no longer applicable as a description of the traffic capacity of the y sub-group. In an alternate routing system the intermediate and final routes will contain varying proportions of overflow traffic and some extension of classical theory is needed for the calculation of circuit requirements on these routes.

If m, n are random variables representing the occupancy states of the x and y sub-groups, the system will be described by the joint probability distribution f(m, n). Kosten (29) has obtained a solution for f(m, n) through the system equations of state but the result is too complex for computation in general use. In 1955 R. I. Wilkinson (30) showed that the overflow traffic could be reasonably well described by specification of two parameters, the mean and variance of the distribution, which is approximated by a negative binomial. Using curves, the mean and variance of the traffic overflowing from given numbers of trunks can be assessed. From the compound traffic with mean and variance equal to the sums of the component traffic parameters, an Equivalent Random Load A is found and a number of trunks S, such that the overflow from S will have the same mean and variance as the compound traffic. Using pure-chance theory the number of trunks Z is then calculated for input traffic A and the required grade of service. The actual number of final route circuits will then be (Z–S).

Ekberg (31) has produced a more exact treatment of the behaviour of overflow traffic. His analysis is based on the use of time derivatives of the call-arrival distributions as descriptive parameters and the method is applicable to the solution of gradings and alternate routing schemes. The process is however far too complex to be applied in traffic engineering practice although it is a valuable analytical contribution to traffic research.

Calculation of Final Route Circuits

Wilkinson's method (30) has already been outlined.

Weighted Choice Method. E. P. G. Wright (32), has developed a semi-empirical method, similar in principle to Wilkinson's, by which the character of the overflow traffic is described by its mean value and the size of the circuit group from which it overflowed. It is known as the 'Weighted Choice' method. In compounding the overflow components, each is weighted by a number (n + 1) where n is the number of trunks from which the particular traffic overflows. A composite traffic is thus obtained with a mean value equal to the sum of the component means and an 'overflow-characteristic' described by the hypothetical choice number obtained from the weighting process described. The subsequent procedure is the same as Wilkinson's—an equivalent random input is obtained and hence the number of final route circuits determined.

Swedish Method. A further semi-empirical method has been developed in Sweden for circuit calculations on the final route. It is based on the following reasoning:—

It is assumed that the final route is initially planned to carry *all* the traffic, and a reduction in the number of circuits is made to account for the traffic which is in fact carried by direct trunks. To ensure that the remaining final route circuits will always be adequate it is assumed that tthe reduction in the traffic capacity of the final route when y (direct) circuits are deducted will be equal to the traffic carried by the *first* y circuits of group.

Methods Adopted. After investigations, a C.C.I.T.T. study group (32), decided to recommend the use of either one of two methods:—

(i) Weighted choice method.
(ii) Swedish method.

for the calculation of circuit quantities on final routes in International networks.

Within European administrations, traffic engineers generally show a preference for Wilkinson's method although there has so far only been limited engineering of alternate routing networks in practice. It is interesting to find that the method is not used within the Bell System. The reasons for this are that it is considered to be over-complex for field use, and that the day-to-day variations in final route traffic are not accounted for. Current practice is to assume that the overflow traffic is effectively random, providing that the sum of the overflow components is less than 20% of the traffic on the final route. If greater than 20% then the overflow component is inflated by 2%.

This simplification works reasonably well in practice since the economic provision on many routes occurs at the stage where the number of direct circuits is approximately equal to the value of the offered traffic. With this arrangement it happens that the ratio of traffic variance to mean is fairly constant and not too far removed from unity so that the assumption of constancy of overflow traffic character does not result in appreciable errors.

Poisson (lost calls held) tables with .03 loss are applied to the total traffic.

Daily Traffic Variations

Because of the high occupancy of the direct routes, the overflow traffic and hence the final route traffic are very sensitive to variations in the level of offered traffic. In some circumstances an increase of 20% in traffic offered to the direct route can double the overflow component. Where the sum of the overflow traffics represents a significant proportion (say $> 25\%$) of the total traffic on the final route, these variations can cause widely fluctuating levels of service. This problem has also been studied by Wilkinson (11). He has shown that the day-to-day variations in both offered load and overflow load could be well described by suitable Gamma distributions (Pearsons Type III distributions). The correlation between the various overflow components has also been studied and a theory devised by which to predict the grade of service on final routes. An extensive field trial has confirmed the accuracy of these predictions and has shown that the variability in day-to-day grade of service can be very great. It becomes apparent that for these types of route a grade of service relating to average busy-hour conditions over an extended period (e.g. busy season) gives little indication of the very poor service which will result on a few high days within the period. For this reason a second service criteria related to conditions on the three or four highest days is also needed. Investigations are proceeding, with the object of producing practical engineering methods, incorporating the new distribution theory, for general field use.

The C.C.I.T.T. is also studying the problems of daily traffic variations on final routes of international trunk networks and has acquired considerable field data for further analysis.

Alternate Routing in Practice

There is a comprehensive scheme for alternate routing in the American trunk switching plan. With Crossbar Tandem equipment, up to 3 routing choices are possible, 4 choices with No. 5 Crossbar and up to 7 with No. 4 Crossbar tandem. About two-thirds of all trunks in the U.S. national trunk network are now operating as part of an alternate routing scheme, in which the first-choice routes carry between 75% and 90% of the total traffic. Extensive use is made of both-way circuits for which they claim the following advantages:—

(i) The increased traffic efficiency of the large group.
(ii) Less administration required in ensuring a correct balance between incoming and outgoing circuits.
(iii) The increased efficiency resulting from the non-coincidence of busy hours. This is particularly important on long East-West circuits where regional time-zone boundaries are crossed.
(iv) Less sensitive to an unusual change in the pattern of traffic dispersion.

The additional costs with both-way circuits are:—

(i) Dual equipment terminations are required at each end. This also results in a faster use of switch availability.
(ii) Relay equipment for change-over and remote 'busy' supervision.

In step by step equipment, both way circuits are not usually economical where the total circuit requirements exceed about 20. In crossbar switching, however, the line terminations are relatively cheap, and commonly the incoming and outgoing terminations are identical. For example, the costs for single and 2-way terminations are 60 and 80 units respectively with Crossbar No. 4 tandem equipment, and 75 and 125 with step-by-step. These economics favour provision of considerably more both-way circuits when crossbar equipment is used and both-way groups of around 100 circuits are not uncommon. It should be noted that the multi-frequency signalling equipment is not associated with the terminations but with the common equipment.

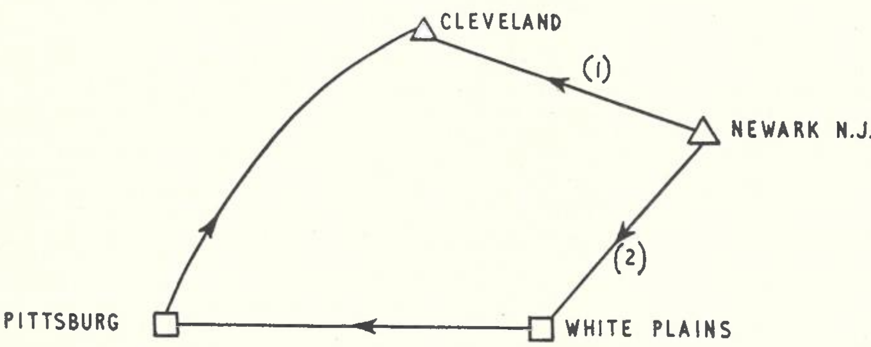
Although some European administrations, notably Germany and Sweden, are planning for extensive alternate routing in their networks, it is surprising to find that little use is made of this type of trunking in most of the other countries —e.g., United Kingdom, Holland, Belgium and France, and that no great future use is planned; the present United Kingdom scheme will limit the routing to one overflow choice at each switching point and in Holland the only overflow centres are Rotterdam and The Hague, these being primarily for security reasons rather than for trunking efficiency. This is mainly due to the relatively short distances involved, the fairly uniform distribution of subscribers and in some cases, to an abundant provision of circuits.

Experience with existing networks has shown that there is a number of practical considerations which should be borne in mind when designing a national alternate routing plan. There are:—

(i) The ever-diminishing cost of carrier, and the fact that channels are always provided in blocks, reduces the need for any great precision in determining circuits between centres directly connected.

(ii) A system employing extensive alternate routing is very sensitive on the backbone route to variations in traffic offered to the direct routes. Subscribers making calls on the backbone route can, at certain times, receive a far worse grade of service than subscribers calling on small direct routes with overflow trunking, unless special trunking arrangements are made. Where the overflow traffic on the backbone route is a significant proportion of the total traffic, the trunking should be split so as to provide individual access to some circuits from the originating subscribers at the transit centre. Also close traffic supervision on the backbone route may be necessary.

(iii) A sudden change in the distribution pattern of trunk traffic can cause severe congestion. A classic example is the change in traffic which occurs on Mothers Day in America. e.g.



On this day, traffic from Newark to Cleveland goes up by 300%. This traffic is diverted to the backbone route Newark, White Plains, Pittsburg, Cleveland and common equipment in White Plains is used. Under these conditions of heavy overload, it is arranged that the overflow from Newark is automatically cancelled and calls are routed through a manual operator. It is better to have delay working on the Newark-Cleveland link than tie up expensive long-distance circuits between the more important centres White Plains and Pittsburg. In America, although there is extensive alternate routing employed, the tendency is not to engineer on the strict economic optimum, but to provide more direct circuits as a service protection. Also the facility for automatic cancellation of alternate routing under prescribed overload conditions and the automatic routing of overflow traffic in such cases to manual positions is a desirable feature of the system.

ANALOGUE AND DIGITAL COMPUTERS IN TRAFFIC RESEARCH

From the earliest days of telephone traffic research there has been a need for an adequate means of verifying traffic theories and assessing the traffic capacity and congestion of trunking patterns too complex for solution by the normal methods of mathematical statistics. For these purposes, measurements on actual traffic are unsatisfactory for various reasons:—

(i) The traffic parameters cannot be suitably controlled, and the traffic conditions are constantly changing.

(ii) With the usual grades of service provided on working equipment, congestion measurements would need to be extended over a large number of busy-hours in order to obtain statistically reliable results. Due to (i) this is not normally possible.

(iii) Tests are often required of new equipment and trunking patterns which are not in service.

Because of these disadvantages, recourse was made to traffic simulation methods. The first simulation studies were performed manually, using tables of random numbers to signify call arrival instants and conversation times (for exponential holding-times). The subsequent "traffic bookkeeping" of all calls and of particular circuits busy, enabled the performance of the hypothetical trunking to be evaluated. These techniques are termed "Throwdown studies".

Analogue Traffic Machines. The labour required for adequate throwdown studies inspired traffic engineers to develop analogue equipment for automatic traffic simulation. The essential block-components of such a device are indicated in Fig. 23.

Ellerman and Fraser (33) were the first to construct such a machine. This was of a essentially mechanical construction using the random displacement of small steel balls dropped onto a larger one as the means of random call generation. Holding times were constant and the duration of the calls was variable by means of fluid flow through a narrow aperture.

Kosten devised a machine in which the random call events were generated by the chance operation of a Geiger-counter in the presence of a radio-active source.

Both these machines had limited outlet capacity and the first traffic computer suitable for a range of practical trunking problems was that of Kruitof (34). Random call generation was controlled by the eccentric spinning of a flat irregular cylinder containing a number of steel dice. Under certain conditions the dice caused operation of a pair of contacts to initiate a call. The remainder of the machine was composed of electro-mechanical equipment — relays, uniselectors, and the instrumentation was by subscriber type meters. Valuable work was performed on this machine concerning the traffic capacities of interconnecting schemes and gradings.

Several other electro-mechanical traffic analogue machines have since been constructed, including one in Sweden (35), and one in Germany, but the first electronic version was developed in England by Broadhurst and Harmston (36), of the B.P.O. This uses an electronic roulette employing eight neon-tube noise generators as the basic random sources. The traffic generator has 256 outlets leading to a distribution table by means of which trunking patterns can be simulated. The trunking connections are made through electronic gating circuits referred to as 'contacts', and the trunk occupancy is simulated on electronic register circuits. Instrumentation is by means of decatron counters, and a neon-lamp display of circuit occupancy is provided for testing. The machine generates events at the rate of 300 per second and the high speed of operation enables the traffic of very many hours to be simulated in several minutes.

Analogue traffic machines of the types described are used extensively for the solution of a variety of traffic problems including:—

(i) Measurement of the performance of interconnecting schemes and gradings.

(ii) Design of alternate routing systems.

(iii) Link System studies.

There is, however, an important range of problems which cannot conveniently be studied in the existing analogue machines. These include:—

(i) Trunking with 'smoothed' traffic input.

(ii) The mixing and partitioning of traffics.

(iii) The effect of selective outlet allocation from gradings.

(iv) General multi-stage trunking problems.

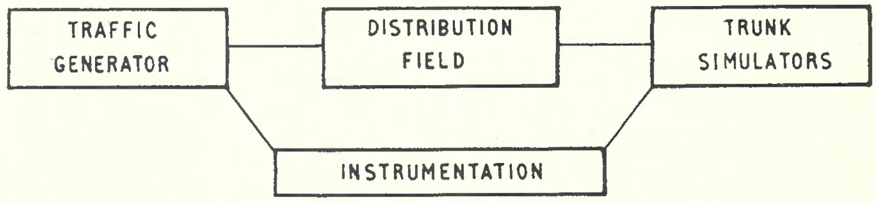


Fig. 23.—Analogue Traffic Machines—Block Schematic Diagram.

Some of these can be simulated with difficulty, but the interconnecting arrangements are quite complex, and the equipment capacity is rapidly used up.

As much of the fundamental traffic work has now been completed, it is important that any new analogue equipment constructed is capable of handling the more sophisticated problems.

Use of Electronic Digital Computers. High speed electronic computers, as used for data processing and scientific study are being used extensively overseas for the solution of telephone traffic problems. Probably their first application to this class of work was the use of the Swedish computer "BESK" in the tabulation of the Erlang loss function over a wide range of values (37). Subsequently, this computer has been used for the solution of a number of specific traffic problems. The work falls into two classes:—

(i) Solution of the theoretical equations of state which describe the system concerned.

(ii) High speed simulation studies based on an extension of the earlier "throw-down" techniques. These are known as Monte Carlo methods. Random numbers are used to indicate the moments of call initiation and termination, and a continuous "book-keeping" is maintained by the computer of the hypothetical states of occupancy of the system being simulated.

Elldin and Carlsson (38), have developed iterative methods with fast convergence for the solution of gradings through their equations of state. The large number of equations and unknowns and the consequent demands on computer storage capacity have precluded use of these methods for other than small (3 group) gradings.

Neovius (39), first developed a computer programme for the solution of traffic problems using Monte Carlo methods. For random number generation he used a modification of the Fibonacci series 1, 1, 2, 3, 5, 8, 13 . . . R_n in the form $R_{n+1} = (R_n + R_{n-1})$ mod. 2^{40} with every second term omitted. The random numbers generate the incoming Poisson traffic directly, but it would be possible to simulate other input traffic forms, either by a suitable generation programme or by storing the random numbers and operating on them to modify the input distribution. Monte Carlo methods have been used in Sweden (40), Denmark and America in the simulation of gradings, link-systems and alternate routing schemes.

With their high operating speeds – BESK generates 2^{18} calls in 15 minutes, and flexibility to a wide range of problems, digital computers should become a most valuable tool in future traffic research.

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STABILITY AND ECHO IN THE TRUNK NETWORK

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1. GENERAL

Subscriber - trunk - dialling demands more from the transmission performance of the trunk network than the present methods of manual-operator control. With STD, skilled supervision by the operator is absent. The transmission facilities must therefore be made more reliable, and the switching equipment must automatically recognise faulty or busy circuits and re-route calls over alternative routes; a process which implies that many trunk channels can be connected in tandem. Because a given link in the trunk network may serve in a variety of complex multi-link connexions, stringent control over its transmission characteristics is necessary to ensure a given standard of performance under all switching conditions. It is particularly important that adequate control of stability and echo should be assured, since there is at present no suitable automatic means of detecting and busying circuits which are faulty in these respects. Moreover, individual subscribers are affected to different extents by echo so that automatic control of this feature would be extremely difficult.

2. STABILITY AND ECHO

Low-loss trunk circuits must generally be provided by the 4-wire method, since the devices used to reduce loss are generally unidirectional. Each end of such a circuit must connect to a 2-wire telephone; the device used for this purpose is a terminating set (or less correctly, a hybrid transformer). Fig. 1 shows a 4-wire circuit with a terminating set at each end. Ideally, the terminating set would permit transmission with no loss from A to B, A′ to B′, C to A, and C′ to A′. Further, it would completely prevent transmission from C to B and from C′ to B′.

In practice, there is a finite, but low loss in the preferred directions, and a finite, but high loss in the prohibited direction. If the latter loss becomes sufficiently low, and the circuit loss between A and A′ is also low, instability can occur; signals can circulate around the path B C′ B′ C B, etc. Under unfavourable conditions, the circuit will oscillate or 'sing', usually at a frequency in the audio-frequency band, and the amplitude of the oscillation, (limited only by non-linearities in the elements of the 4-wire circuit) will be sufficiently large not only to render conversation impossible, but also to interfere with other circuits.

However, there is also danger in even approaching the point where the circuit 'sings'. As the round-the-loop loss approaches zero, the frequency response of the circuit is distorted. The loss is lower at the frequency at which the circuit is ultimately going to 'sing', and higher at other frequencies where the round-the-loop phase change may be approaching odd multiples of π radians. Consequently, the intelligibility of the circuit is reduced, and the subscriber has difficulty in conducting his conversation, due to 'hollowness' or 'ringing'. The effect is similar to that of listening at one end of a long pipe, with a speaker at the other end.

When the 4-wire line connecting the two terminating sets in Fig. 1 is very long, the propagation time of the signals from B to C′ and from B′ to C delays the signals around the loop. Suppose a pulse signal is sent into the 2-wire line at A. The pulse will travel to C′, and some of its energy will pass through the terminating set in the prohibited direction and return to A via B′ and C. If the delay around the loop is more than some tens of milliseconds, a speaker using the circuit would hear a distinct echo of his own voice while talking. The annoyance value of this echo increases as the delay increases, and naturally it also increases as the amplitude of the echo increases relative to the speaker's own voice.

We have discussed only qualitatively the phenomena of instability and echo; the next sections explain the factors which govern them.

3. RETURN LOSS AT THE TERMINATING SET

We have seen that the cause of instability and echo is the unwanted transmission between C′ and B′ and between C and B in Fig. 1. What governs this transmission, and how can it be made a minimum?

For the purpose of this section, it is sufficient to regard a terminating unit as a 4-port network (Fig. 2) in which signals incoming from the 4-wire circuit at the 'receive' port can appear at the remaining three ports. If Z_1 is identical to Z_2, (the ideal case) then the available power divides equally between Z_1 and Z_2 and no signal appears at the 'transmit' terminals. If this condition could be guaranteed, there would be no instability or echo effects in the trunk network.

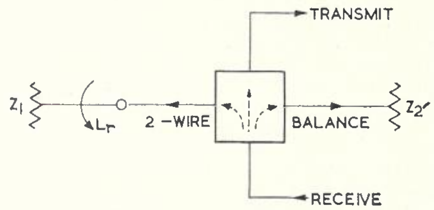

Fig. 2.—Terminating Set and Return Loss.

In practice, Z_2 must generally be fixed, while Z_1 represents all the possible terminating conditions which may be connected to the 2-wire terminals of the terminating set. It could be the impedance of a telephone set in the same building; of a telephone at the end of a long subscriber's line; or of a telephone connected to a distant exchange as seen through a 2-wire trunk line having some loss. The range of Z_1 can clearly be quite large, and it is impossible for the fixed impedance Z_2 to provide a perfect match to any but a very few of the available circuits.

The amount of unwanted power passing from the 'receive' to the 'transmit' terminals is a function of the ratio Z_1/Z_2; the greater the departure from $Z_1/Z_2 \equiv 1$, the greater the unwanted power at the 'transmit' terminals. The effect can be understood by imagining that the received power incident at the 2-wire terminals is absorbed fully by Z_1 if $Z_1/Z_2 \equiv 1$ and is reflected back into the 2-wire terminals of the terminating set with a finite loss L_r when $Z_1/Z_2 \neq 1$. The magnitude of L_r is $20 \log_{10} |(Z_1 + Z_2)/(Z_1 - Z_2)|$ dB (see Appendix I). Note that Z_1 and Z_2 are vector values, but that L_r depends only on the modulus of the impedance function. L_r is known as the return loss of Z_1 against Z_2.

The common value adopted for Z_2 is 600 ohms in series with 2 microfarads. Using the known distribution of types and lengths of subscribers lines, and an assumed distribution for the future of half 300-type and older telephones, and half 400 or 700-type telephones, the average and standard deviations of return loss at the M.D.F. of a telephone

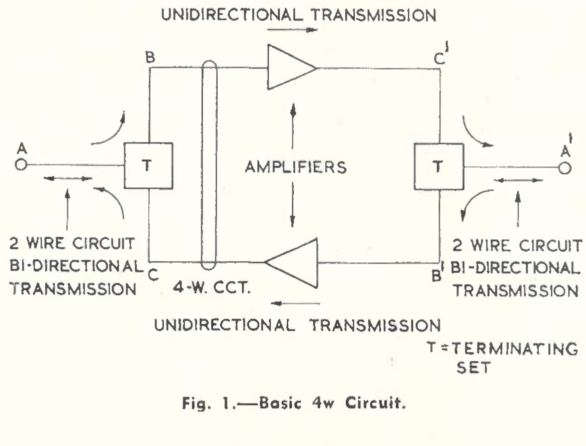

Fig. 1.—Basic 4w Circuit.

* See page 79.

exchange has been calclulated against this compromise value of Z_2. It must be borne in mind that not only does the value of return loss vary between different kinds of 2-wire circuits, but it also varies over the voice-frequency range on each individual circuit.

It is shown in later sections that the frequencies of importance in stability calculations are those at the upper and lower ends of the audio-frequency range, while for echo calculations, the important frequencies are those in the centre of that range. Thus we obtain different values of return loss and its standard deviation according to the use to which the return loss data are to be put. In stability calculations, the data yield an average loss of 7.5 dB and a standard deviation of 2.5 dB as representative values for subscribers' lines at the M.D.F., while for echo calculations the corresponding values are 9dB and 2.5 dB. (See Appendix 2 for a discussion of the "statistical approach".)

If the losses of 4-wire lines are to be kept low, it can be shown that these values of return loss would be too low to provide adequate stability and echo performance, and that they must be increased.

The return loss of the terminating set can be improved, at the cost of extra loss in the 2-wire circuit, as shown in Fig. 3. An attenuator (or pad) of char-

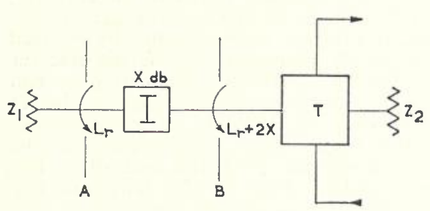

Fig. 3.—Improving Return Loss.

acteristic impedance Z_2 and loss X dB is interposed between the terminating set and Z_1. The impedance at A looking towards Z_2 is still Z_2 and the return loss referred to point A is still L_r. The return loss at the terminating set (point B) is increased to $(L_r + 2X)$ dB. A signal passing from B to A will decrease by X dB on passing the pad, by L_r dB on reflection at Z_1, and by a further X dB on passing the pad from A to B. The pad may be imagined to mask changes in Z_1 from appearing in full at point B. (With a large value of X, extreme values of Z_1 approaching short circuit or open circuit, would have negligible effect at B.)

To produce minimum loss penalty on the circuit, the value of X should be kept small, consistent with achieving sufficient return loss improvement. A value of 3 dB has been chosen as a suitable compromise to insert between subscribers' lines and terminating sets in the same exchange; this will raise the average return loss at the terminating set to 13.5 dB (stability) and 15 dB (echo) with standard deviations as before.

When the subscriber's line does not terminate in the same building as the terminating set of the 4-wire circuit to which it is connected, but is connected via a 2-wire line having some loss, a pad will be unnecessary if the loss of the 2-wire line is about 3 dB or more, while a pad of such value to bring the 2-wire loss to about 3 dB is necessary in other cases.

4. FACTORS AFFECTING STABILITY

4.1. General

In the 4-wire circuit of Fig 1, it is possible under certain conditions for the overall round-the-loop gains to exceed the round-the-loop losses at a given frequency, and simultaneously for the round-the-loop phase change at the frequency to be a multiple of 2π radians. Under these conditions, the components of noise signals always present in such a circuit commence to build up an oscillation at the critical frequency, the amplitude of which is determined by non-linear devices (e.g. amplitude limiters or overloading amplifiers) in the circuit.

The basic 4-wire circuit of Fig. 1 is redrawn in Fig. 4 to show the factors affecting stability. With all losses in decibels, we assume a 2-wire-to-2-wire loss of e, identical in each direction, and return losses of L_{ra} and L_{rb} at ends A and B respectively. The round-the-loop loss starting from end A, is then $e + L_{ra} + e + L_{rb}$. Assuming that the phase condition around the loop is such as to support oscillation at some frequency, then the condition for oscillation is $2e + L_{ra} + L_{rb} = 0$ and if e_{min} is the minimum circuit loss at the point of oscillation, then

$$2e_{min} = -(L_{ra} + L_{rb}) \quad \ldots\ldots\ldots\ldots \quad (1)$$

However, all the elements of this equation are subject to variations, and the following paragraphs deal with each in turn and show how equation (1) must be modified to apply to the practical situation.

4.2. Circuit Loss

Circuit loss varies in three ways—with time, with frequency and with signal level.

Variation with time occurs due to variation of system loss due to climatic conditions, variation of amplifier gains with supply voltage fluctuation, and to other factors. Although regulating systems minimise these variations, control is still imperfect, and residual variation of circuit loss with time is sufficiently large to require to be taken into account.

Measurements in the Australian network have led to the assumption for calculation purposes of an average value $L_t = 0$ and a standard deviation $S_t = 2$ dB for the variation of 'round-trip' loss with time. The latter value corresponds to a correlation of about 0.2 between variations in opposite directions of transmission in the 4-wire circuit. An average value of 0 dB implies that increases of loss with time are just as likely as decreases. The effect is assumed to add randomly in tandem-connected 4-wire links; thus for an n-link circuit the overall standard deviation of variation of a circuit loss with time would be $\sqrt{n}S_t = 2\sqrt{n}$ dB.

Variation with frequency is important in stability calculations; in practice, the return losses L_{ra} and L_{rb} become much lower at the upper and lower ends of the telephone channel bandwidth than at mid-frequencies, and the incipient oscillation frequency is likely to be in these regions. Therefore it is the circuit loss at the upper and lower ends of the frequency band, rather than that at line-up frequency (e), that must be considered.

The loss/frequency characteristic of a trunk channel tends to rise in these regions, compared with middle frequencies; furthermore, close control of the characteristic is not economical, and different circuits will show different losses at a given high or low frequency. The average of this variation, compared with circuit loss at line-up frequency, is taken as $L_f = 1$ dB for the 'round trip', with a standard deviation of $S_f = 0.9$ dB.

When n links are connected in tandem the average values will add arithmetically, and the variations will be assumed to add randomly. For an n-link tandem connection, therefore, the average loss variation with frequency will be $nL_f =$ n dB, and the overall standard deviation will be $\sqrt{n}S_f = 0.9\sqrt{n}$.

Variation with signal level occurs due to non-linearity in the overall input-voltage/output-voltage characteristic of an active communication channel. The loss of the channel is less for a small-amplitude signal than for a tone of standard test level. Since the loss e is known only from the measurements with normal test tone, we must make an adjustment to take account of the actual loss which applies to signals at about noise level (from which an incipient

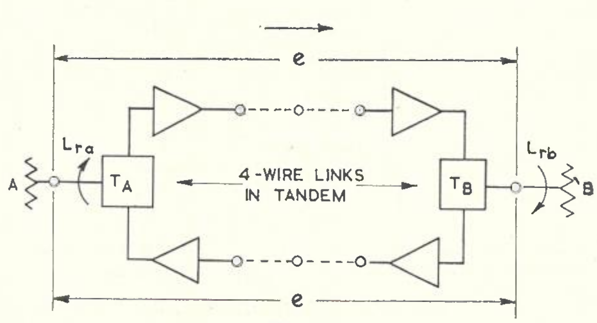

Fig. 4.—Factors Affecting Stability.

oscillation must build up). The difference has been taken as 0.1 dB per direction per link—that is, the actual circuit loss for noise signals is assumed to be 0.1 dB less than for test tone. The variation (L_l), being a function only of signal level, will add arithmetically for each direction of transmission and for the number of links in the built-up connection. Thus the value for an n-link tandem connection will be $2nL_l = 0.2n$ dB.

Return Loss

Variation of return loss has been discussed in para. 3 for normal conditions of termination with subscribers' telephones. The average value of L_{ra} and L_{rb} is 13.5 dB, with a standard deviation of 2.5 dB. Under fault conditions, the return loss can become much lower. In the extreme case of a short-circuit close to the 2-wire or balance terminals of a terminating set, the return loss is zero; that is, all the received power is returned to the sending end. There is a small probability of such a fault occurring at one end of a built-up connection, and a quite remote probability of simultaneous faults at both ends. These circumstances naturally favour instability.

Stability in an n-link Circuit

We now modify equation (1) to take account of the factors just discussed, and apply it to the general case of a 4-wire-switched, n-link circuit.

If M dB is a margin which must exist between the actual round-the-loop loss and the loss corresponding to the oscillation point, then this margin must be **added** to the minimum loss $2e_{min}$; therefore we add M to the right-hand-side of the equation.

The minimum circuit loss must be **decreased** to compensate for the increase in loss at low or high frequencies compared with line-up frequency; we therefore subtract nL_f from the right-hand-side of the equation.

Similarly, the factor $2nL_l$ must be **added** to the right-hand-side to account for the reduced loss with noise signals compared with test tone.

These first three items have dealt with the average values of the variables; now we account for the effects of the range of variation of the factors, as measured by their respective standard deviations. To simplify the analysis, we assume that each of the variations has a normal distribution, and that they add randomly. Then to cater for those variations which **reduce** circuit loss, a factor proportional to the r.m.s. sum of the various standard deviations must be added to the right-hand-side of the equation. (Variations which increase circuit loss are irrelevant here.) We then have:

$$2e_{min} = -(L_{ra} + L_{rb}) + M - nL_f + 2nL_l + q\sqrt{nS_t^2 + nS_f^2 + S_{ra}^2 + S_{rb}^2}$$

or

$$e_{min} = \tfrac{1}{2}[M - L_{ra} - L_{rb} + n(2L_l - L_f) + q\sqrt{n(S_t^2 + S_f^2) + S_{ra}^2 + S_{rb}^2}\,] \quad (2),$$

where q is a factor dependent on the probability of exceeding the stability limit. (See Appendix 2.)

By inserting appropriate values, (2) may be evaluated for any particular circumstances.

Experience has shown that to avoid "hollowness", it is desirable that the margin M in the talking condition is at least 7 dB at line-up frequency. There are two approaches to the matter of "hollowness"; the first assumes that the **band-end values of the variables are effective.** Here, the return loss L_{ra}, L_{rb} is lower than for the mid-band case, but this effect is offset by the additional circuit loss of each link, compared with the mid-band loss.

The second approach to "hollowness" assumes that it is the **mid-band frequency range which controls** the subjective effects of hollowness; thus the factor L_f is taken as zero, and the higher (mid-band) values of L_{ra} and L_{rb} are applied.

The first approach yields:

$$e_{min} = \tfrac{1}{2}[-(0.8n + 20) + q\sqrt{4.81n + 12.5}\,] \text{ dB} \quad (3)$$

while the second approach yields:

$$e_{min} = \tfrac{1}{2}[-(0.2n + 23) + q\sqrt{4n + 12.5}\,] \text{ dB} \quad (4)$$

Cases of actual oscillation may be calculated for one end open-circuit (or short-circuit):

$$e_{min} = \tfrac{1}{2}[-(0.8n + 13.5) + q\sqrt{4.81n + 6.25}\,] \text{ dB} \quad (5)$$

and for both ends open-circuit (or short-circuit):

$$e_{min} = \tfrac{1}{2}[-0.8n + \sqrt{4.8ln}\,] \text{ dB} \quad (6)$$

Equations (3), and (4) are shown graphically in Fig. 5, while equations (5) and (6) are shown separately in Fig. 6. The conclusions from these results are discussed in para 6.

5. FACTORS AFFECTING ECHO

5.1. General

Echo phenomena are closely related to the conditions for stability already described. A pulse signal sent from A (Fig. 4) is reflected from end B with a loss of L_{rb}. The transmission of such a pulse (or burst of speech energy) is not instantaneous. Its group velocity is a function of the type and length of transmission facility in use, and further delays occur in the channel filters of carrier telephone systems. The sum of these delays on the round trip causes a talker to hear a disturbing echo of his own voice when the delay exceeds some tens of milliseconds.

The general transmission problem with respect to echo is to keep the overall 2-wire-to-2-wire loss (e) of the n-link, 4-wire-switched tandem-connected circuit to as low a value as possible, consistent with adequate margin to allow for the variations of circuit loss and return loss described in earlier paragraphs, variations in subscribers' tolerance to echo, variations in the length (delay) of multi-link circuits, and variations in the different subscribers' lines encountered.

The following paragraphs discuss each of the elements of the problem, and then derive a design to ensure satisfactory service to the subscriber with respect to echo for all lengths of circuit and all combinations of links.

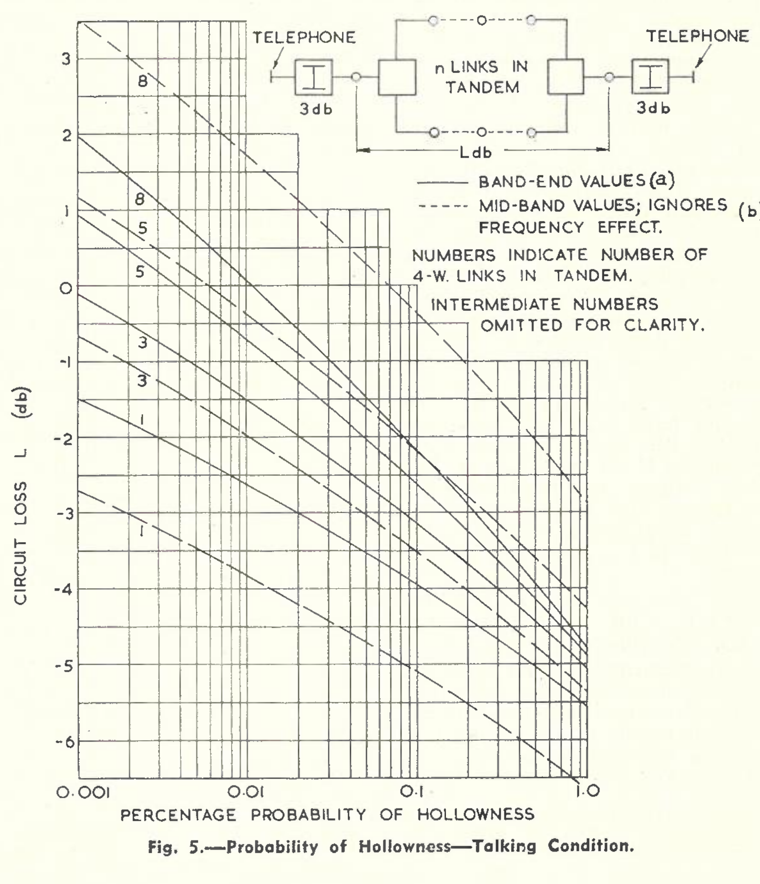

Fig. 5.—Probability of Hollowness—Talking Condition.

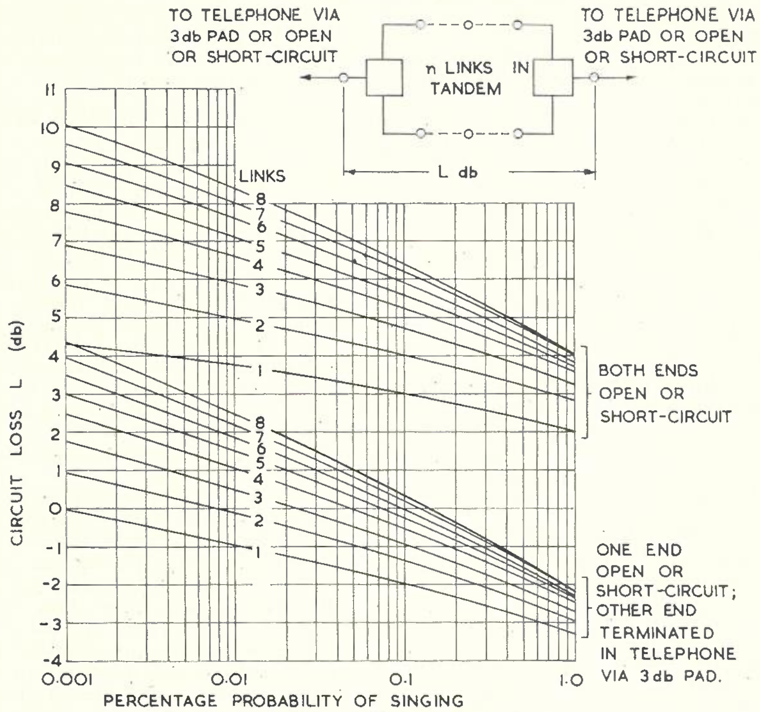

Fig. 6.—Probability of Singing—Fault Conditions.

5.2. Echo Tolerance

Although the C.C.I.F. has studied the subject of echo tolerance (2), the only published quantitative statistical assessments of the effects of echo are of American origin; in the absence of similar information relating to Australian speech, observers, and equipment, the American experience is the best available evidence.*

In the tests a number of observers spoke into a normal telephone, the receiver of which was connected to the transmitter via a variable attenuator and a variable delay device, so that the amplitude and delay of the simulated echo could be controlled. The telephone circuit simulated a subscriber's line close to the terminating set in Fig. 4. The tests yielded a criterion: "loss in echo path just satisfactory to the average observer" for values of delay from 0 to 100 ms. Two sets of tests were made by the same organisation, one set before 1953 (3), and a revised set in 1954 (4). The earlier data have been and are being used by the Bell System in their trunk network in the U.S.-Canada region. The later data "will be substituted when the time is appropriate" (5).

We shall adopt the later data, which are illustrated in Fig. 7 in terms of loss in echo path (L_e) as a function of echo delay. The standard deviation of this factor (S_e) is 5 dB.

5.3. Subscriber's Line Loss

The measurements of echo tolerance were for "subscribers near the toll office", i.e., for a negligible loss between the 2-wire terminals of the terminating set and the subscriber's telephone. In practice, however, this attenuation is not negligible. We have shown earlier that a 3 dB pad or its equivalent in 2-wire trunk loss will always be interposed between a subscriber's line and a terminating set. Furthermore, the effects of the loss of the subscriber's line itself must be taken account of in terms of average values and standard deviation.

Based on a distribution study of actual subscribers' lines, we may assume an average loss L_s of 5 dB between subscribers and the 2-wire terminals of terminating set, and a standard deviation S_s of 1.6 dB. This includes the effect of the 3 dB pad or lossy terminal link which will always be present when the subscriber is connected to a low-loss 4-wire trunk circuit,

5.4. Circuit Loss

By "circuit loss" we mean the loss defined by e in Fig. 4. The variation of e with time is still effective, and the same values as described in paragraph 4.2 apply: $L_t = 0$; $S_t = 2$ dB. Variation with frequency and signal level have no influence on echo performance. Mid-band echo signals control the subjective effects of echo, and the signals under consideration are speech, and near enough in amplitude to test tone to render negligible any non-linearity effects.

5.5. Return Loss

Only the talking condition is applicable and the "echo" return loss figures quoted in paragraph 3 will apply: $L_r = 15$ dB, and $S_r = 2.5$ dB.

5.6. Echo Delay

The group velocity of an electrical signal depends on its frequency and the medium in which it is propagated. For speech signals or their carrier-converted equivalent, it is about 13 miles/ms in a loaded voice frequency cable, about 170

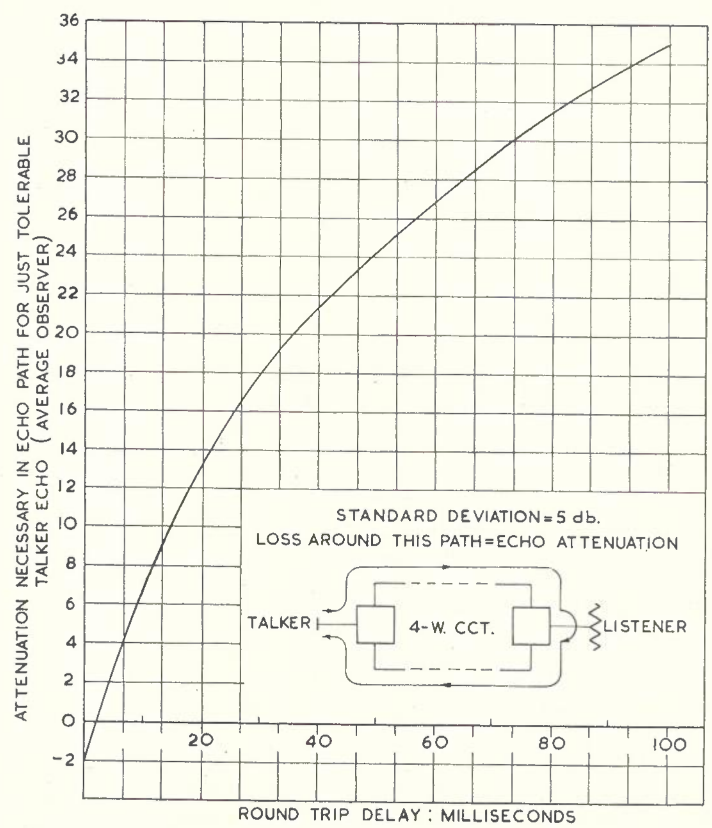

Fig. 7.—Echo Tolerance vs. Echo Delay.

*But reference (12) was published after this article was prepared; it deals with British Post Office measurements.

miles/ms in coaxial cable, and about 180 miles/ms in an open-wire carrier or radio system. There are few trunk circuits of significant length employing voice frequency cable. The majority of circuits are at present via open-wire carrier systems, and in the future, coaxial cable and radio bearers will be used to an increasing extent. The Australian network is therefore (and will continue to be) a high-velocity system, and little error will arise from adopting a single velocity figure for the whole network. We shall assume a velocity of 170 miles/ms, or a one-way delay of 5.9 ms/1000 miles. The round-trip delay would therefore be 11.8 ms/1000 **route** miles.

This is not the only cause of delay. Every channel filter in a carrier telephone system introduces delay, such that a channel including a transmit channel filter and a receive channel filter produces a one-way delay of about 1.5 ms (6) (7). The round-trip delay is double this: 3 ms. Again, we make the simplifying assumption that all trunk circuits are carrier-derived.

Thus the net delay suffered by a signal in the round trip on an n-link call is a function of circuit length and number of links:

$T = 3n + 11.8D$ milliseconds .... (7)

where D = route length in thousands of miles.

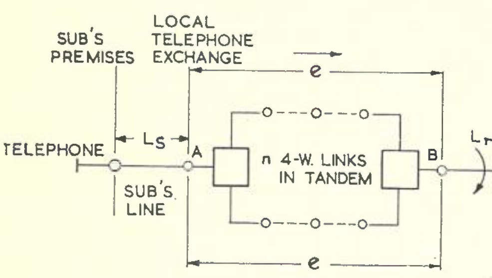

Fig. 8.—Echo Conditions.

5.7. Echo in an n-link Circuit

In Fig. 8 a simplified approach shows that the echo amplitude of a signal originating at X, measured at X, will be:

$L_e = (L_s + e + L_{rb} + e + L_s)$ dB with respect to the original signal

$= (L_{rb} + 2e + 2L_s)$ dB

or $2e = (L_e - L_{rb} - 2L_s)$ dB

Now if we define L_e as the minimum **tolerable** loss in the echo path (Fig. 7), this sets the minimum tolerable circuit loss e_{min}:

$2e_{min} = (L_e - L_{rb} - 2L_s)$ .... (8)

Equation (8) does not account for variations in its components, and the quantity $2e_{min}$ must be increased to cover the probability of the nominal component losses being reduced. We therefore add a term to the right-hand-side of the equation proportional to the r.m.s. sum of the various standard deviations; and express in terms of e_{min}:

$e_{min} = \frac{1}{2}[L_e - L_{rb} - 2L_s + q\sqrt{2S_s^2 + nS_t^2 + S_r^2 + S_e^2}\,]$ .... (9)

where q depends on the assigned probability that intolerable echo will be experienced (Appendix 2).

It has already been shown that L_e is a function of echo delay time, and that echo delay time is a function of both route length and number of tandem 4-wire-switched links. Thus e_{min} can be expressed only in terms of both of these factors.

Equation (9) has been evaluated for up to 8 tandem-connected links as a function of route length for 0.2%, 1% and 5% chances of intolerable echo, and the results are shown in Figs. 9, 10, and 11 respectively.

Figs. 9 to 11 show that the loss of a built-up connection for a given route length must be increased as the number of links in the connection increases and as the route length increases. Thus in Fig. 10, if a 2000-miles circuit is provided by a single link, its minimum loss should be 3.6 db, while the minimum loss of a 2-link circuit of the same route distance would be 4.5 dB, and 6.3 dB if a 4-link connection.

The lines AA' and BB' in Figs. 9 to 11 indicate practical limits imposed by Australian conditions; above AA' and below BB' the curves are meaningless for application to the Australian trunk network.

Now, ingenious though modern trunk switching systems are, it is not yet possible for them to determine the number of links and their total route length in a multi-link connection and then adjust the overall loss of the built-up circuit accordingly; we therefore seek a one-link attenuation design which can be applied to every trunk circuit, and yet will ensure adequate echo performance on multi-link calls of any length.

To allow random addition of links of any length and in any numbers in tandem up to the maximum, it follows that the loss design for a single link must be of the form (a + Db) dB, where a and b are constants, and D is the route distance. In the interests of having a minimum loss on all calls, it also follows that a and b must be as small as possible consistent with tolerable echo performance. Further, the resulting design must simultaneously give satisfactory performance with respect to stability.

The problem, then, is to use the information of Figs. 9 to 11 and to translate it into a simple, though approxi-

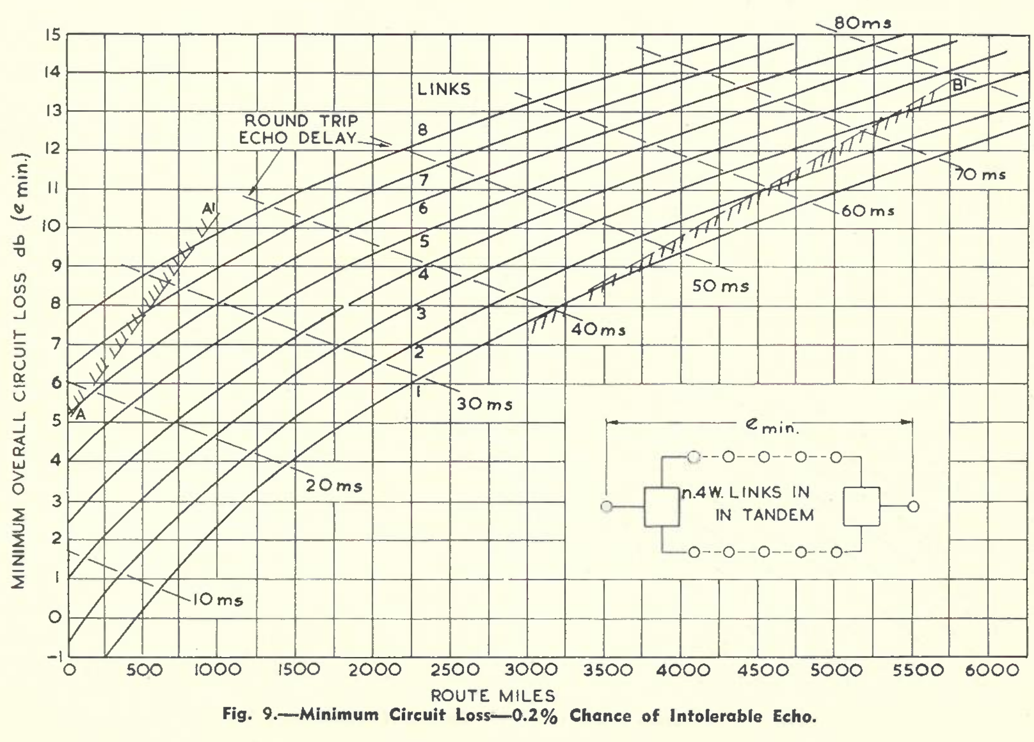

Fig. 9.—Minimum Circuit Loss—0.2% Chance of Intolerable Echo.

mate, a + bD relationship, for application to each individual 4-wire link in the trunk network.

The information of each of Figs. 9 to 11 requires condensation before it can be used to provide a single-link design. We achieve this condensation as follows:

If the co-ordinates of each curve in, say, Fig. 9 are divided by the number of links (n) represented by that curve, we obtain a family of curves which intersect each other. We extract only the intersection points of the curves n = 1, n = 2; n = 2, n = 3; n = 3, n = 4; etc., and take the locus of these intersections as a design basis for one link. It will be seen that this procedure ensures that the resulting design will meet multi-link requirements as specified by the original curves of Fig 9.

The locus of the intersections is substantially a straight line, and the corresponding 'least squares' line is shown as the '0.2%' line in Fig. 12. By a similar process, Fig. 10 yields the '1%' line, and Fig. 11 yields the '5%' line. The equations to these lines in the form a + bD are also shown in Fig. 12.

6. TRUNK CIRCUIT LOSS DESIGN

We have now derived a range of information on instability (Figs. 5 and 6) and on echo (Fig. 12). We shall now consider this information in the light of design criteria in other countries and then derive a single-link circuit-loss design which will apply to every 4-wire circuit in the trunk network.

In the U.S.A. it has been stated (8) that a design based on 1% chance of intolerable echo is satisfactory, and that this design will also be generally satisfactory to avoid 'singing'. No reference

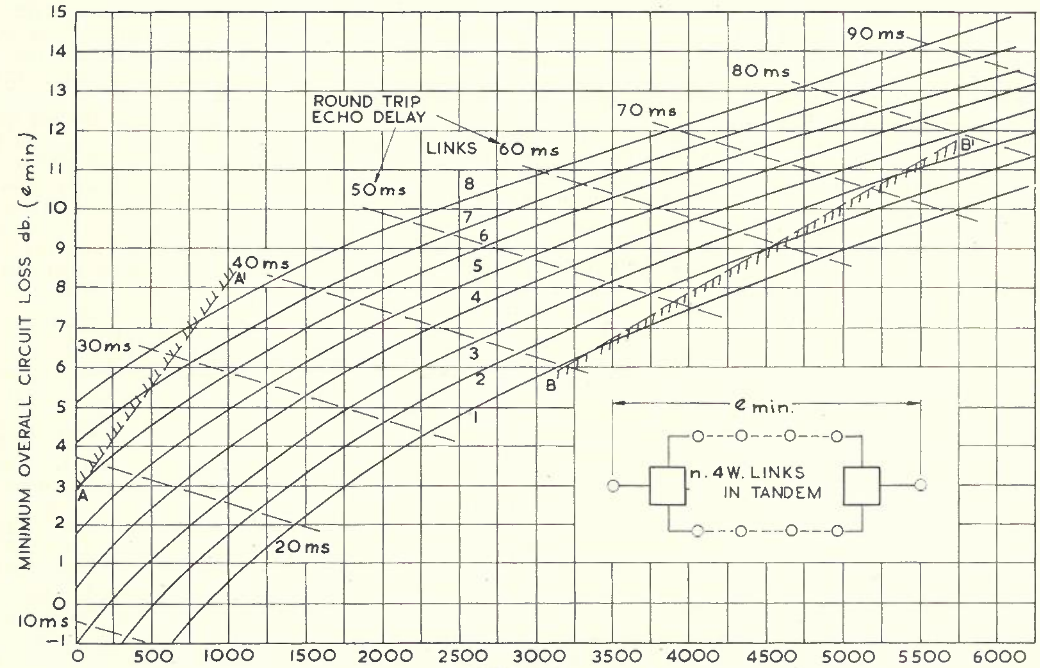

Fig. 10.—Minimum Circuit Loss—1% Chance of Intolerable Echo.

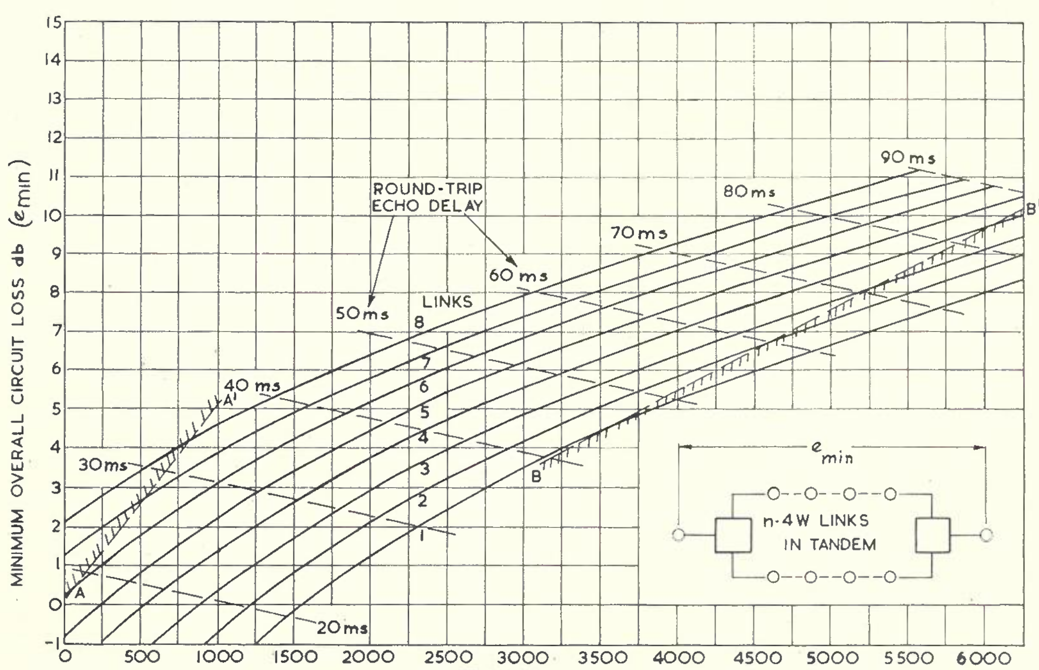

Fig. 11.—Minimum Circuit Loss—5% Chance of Intolerable Echo.

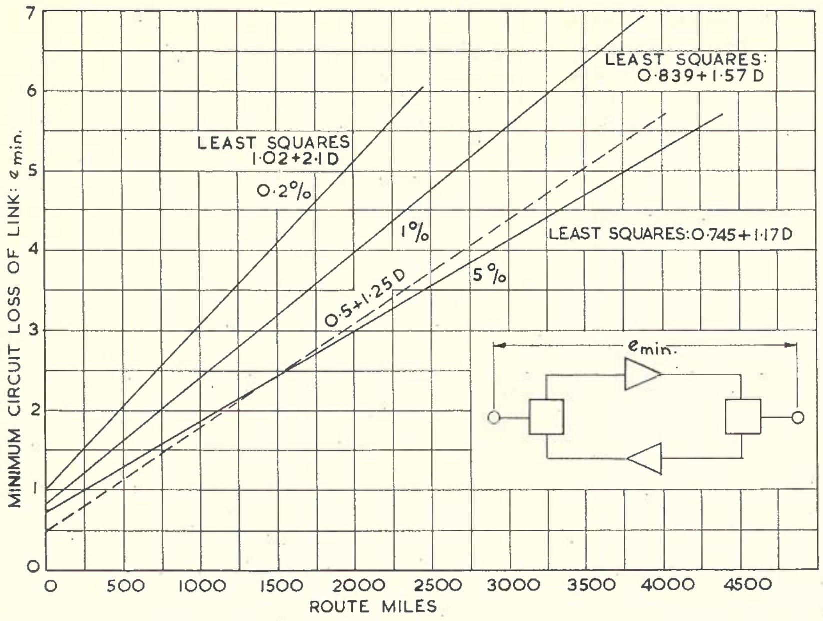

Fig. 12.—Loss Design for Single Link: Derivation.

is made to 'near-singing' or 'hollowness'.

In Europe, a 0.001% chance of singing has been suggested as a suitable stability criterion (6), (7), while an additional criterion of 0.1% chance of reducing the singing margin below 6dB has been suggested to the C.C.I.T.T. (9).

Although these figures are useful to this study, we take the view that there are no 'best' numbers which represent stability and echo criteria. Although the use of such probability criteria is convenient in estimating the effects of changes in design, their use as design objectives is difficult to justify.

Would the public be substantially less satisfied with its telephone service if it experienced one unstable call in ten thousand, rather than one in a hundred thousand? Would a telephone administration be inundated with congratulatory messages if echo effects were discernable on only 0.2% of calls, instead of on 1%?

The approach we shall adopt is this:

(a) Assume no echo-suppressors are used in the network;
(b) With the results of paragraphs 4.4 and 5.7 in mind, and, assuming a 1-link loss design to be of the form (a + bD) dB, assign a and b so as to minimise the loss on as many actual trunk calls as possible;
(c) Determine the stability and echo performance corresponding to this design (from Figs. 5, 6 and 12): decide whether these are satisfactory;
(d) From the final design basis (a + bD), prepare a 'step' design substantially equivalent, in which the circuit loss advances with route length in ½dB steps. (Without this 'step' design, we should be in the position of adjusting each trunk circuit to impracticable values; for example, a Melbourne-Sydney circuit could require a design loss of 1.13 dB. It is more realistic to take account of setting-up inaccuracies, and to ease the lining-up and maintenance task by using only integral steps of ½ dB);
(e) Check for compliance with international standards for overall loss.

From Fig. 12, we find that for between 0.2% and 5% chance of intolerable echo, we require a fixed loss component in each link of between 1 and 0.75 dB, i.e., the factor a in the a + bD formula. Now it so happens that the converging ends of the three lines in Fig. 12 are derived from the higher-n intersections—that is, this fixed loss per link is required to ensure freedom from troublesome echo effects only for large numbers of links in tandem.

Could this basic loss per link be safely reduced from the suggested range of 0.75 to 1 dB? Several factors lead us to believe that it could:

- The great majority of trunk calls are over comparatively short distances; only about 15% are over 100 miles (Fig. 13). Because of this, and because of the provision of an increasing amount of direct-routing in the future trunk network, multi-link calls should be only a very small proportion of the total;
- Any basic loss penalty built into each link to safeguard a very small number of multi-link calls will unavoidably and unnecessarily penalise the vast majority of all calls.
- Our approach so far has sought to avoid the use of echo-suppressors; however, if a reduction of the basic loss per link entails a high probability of intolerable echo conditions, then echo-suppressors can always be added to the longer inter-capital-city links.

Therefore, we investigate the possibility of reducing the basic loss (a) from the 0.75 to 1 dB range suggested by Fig. 12 to a nominal 0.5 dB, and we choose a gradient (b) which is a compromise between a too-severe attenuation penalty and a too-severe echo penalty.

What is a suitable value for (b), having assigned a = 0.5 ? A possible range of values is between 1.2 and 1.3; an examination of the effect of variation of b over this range has been made, and the results are as follows:

The effect of the change of gradient is only small at moderately short distances; an increase in gradient reduces

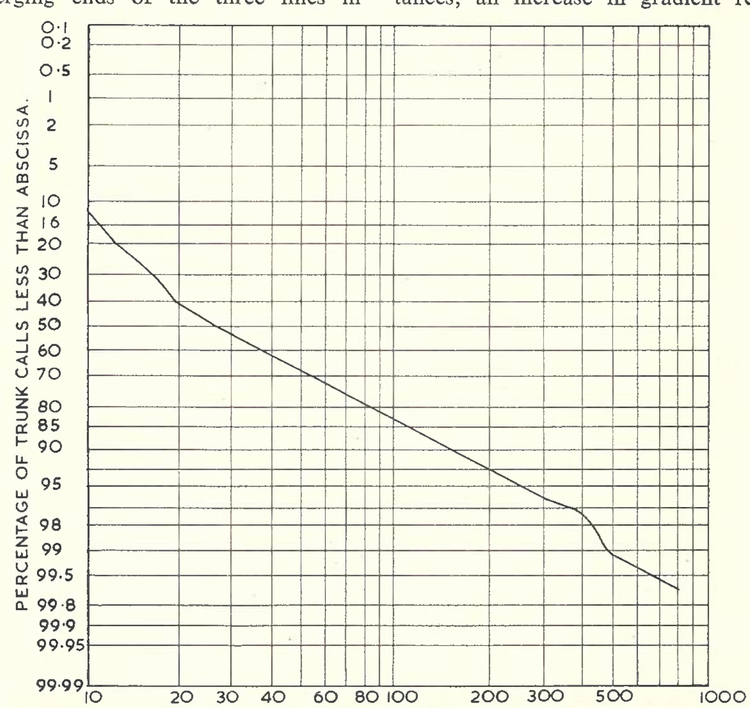

Fig. 13.—Radial Distance of Trunk Calls (1958).

the probability of experiencing intolerable echo at the greater distances. With a gradient of 1.3 dB/1,000 miles, cases of intolerable echo would always be less than 5% for any number of links and for any distance. A gradient of 1.2 dB/1,000 miles increases the chance of intolerable echo to more than 5% at all distances.

A value of 1.25 dB/1,000 miles, with a slightly worse echo performance than that with 1.3 dB/1,000 miles (but with less loss penalty) has been chosen as a suitable compromise, and the results are shown in Fig. 14. It will be seen that the worsening of echo performance (increase in probability of intolerable echo) increases only slowly with number of links and distance; the great majority of trunk calls will have an echo performance of less than 1%.

If a 1% echo performance has been judged to be a limiting condition in the U.S.A., we must anticipate the possibility that an echo performance of up to 5% in the few long-distance calls will not be satisfactory to the Australian public. Accordingly we must arrange for the provision of echo suppressors on circuits between Main Trunk Centres if required.

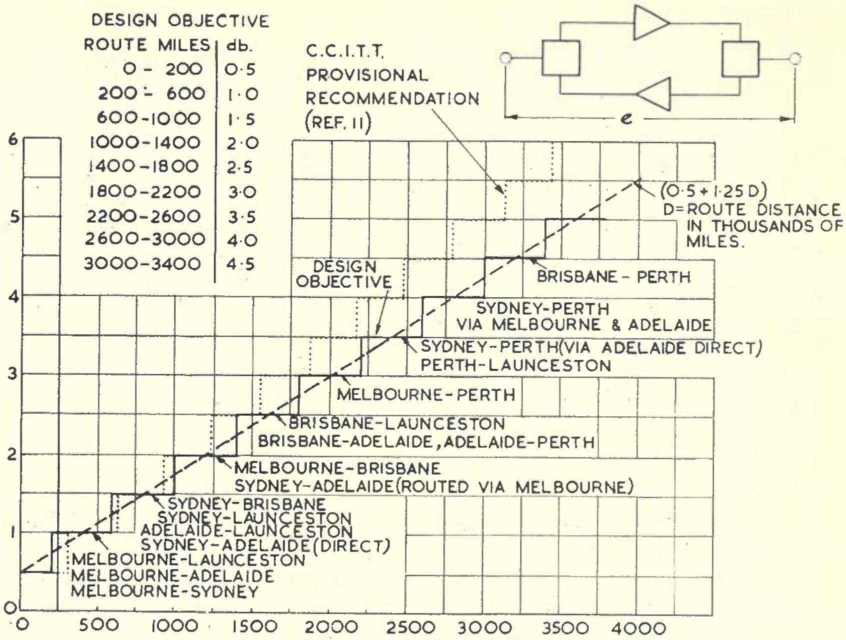

Fig. 15.—Circuit Loss Design Objective.

We have tentatively selected a design basis e = (0.5 + 1.25 D) based on echo performance; we now test it for its stability performance.

For both the 'hollowness' criteria in Fig. 5, we find that in the talking condition, for any number of links, there is always less than 0.001% chance of experiencing 'hollowness'. Thus we judge that the chosen design will ensure satisfactory freedom from 'hollowness'.

Fig. 6 shows that with a fault condition which open-circuits or short-circuits the 2-wire end of a built-up connection, there is less than 0.002% probability of singing on a circuit with 7 or 8 links, about 0.002% on a circuit with from 3 to 6 links, and 0.001% or less on a 2-link or a 1-link circuit. We judge this to be a satisfactory performance.

Fig. 6 also shows the very remote fault condition of both 2-wire ends open or short circuit. The upper group of curves shows that this condition is outside the range of the data; however, the probability of singing has been calculated for zero-distance links (the worst condition) of 0.5 dB loss each. The probability of singing is as follows:

No. of links in tandem:	1	2	3	4	5	6	7	8
Approximate percentage probability of singing:	21	12.5	8	5	3.25	2.2	1.4	1

These probabilities are high. However, the conditions yielding these probabilities have a very low probability of occurrence, and since the overall probability of the *event* of singing (due to both-ends being open or short-circuit) is the product of these two probabilities, we judge that performance in this respect should also be satisfactory.

Steps (b) and (c) described earlier in this section have now been completed. We now proceed to step (d): the 'step' design equivalent to the (0.5 + 1.25D) design. It will be observed that the variable component of this formula corresponds to 0.5dB per 400 miles. Fig. 15 shows the basic (0.5 + 1.25D) line (dashed), and superimposed on it, to yield about equal errors above and below, is the corresponding 'step' design. The initial step of 0.5dB extends to 200 miles, thus embracing the vast majority of 4-wire circuits in the trunk network. Fig. 15 also shows the design losses for various interstate links.

It should be noted that the loss described in Fig. 15 is shown as that between the 2-wire terminals of the two terminating sets, for simplicity. If the circuit is 4-wire-switched, as would be expected in the future network, then the loss in each direction *between switches* would be 7dB less than this, on account of the 3.5dB loss in each terminating set. (Fig. 16a).

The present analysis has, for simplicity, assumed a 3dB pad or an equivalent minimum loss between the 2-wire terminals of a terminating set and the subscriber's telephone. About the same electrical conditions can be achieved by omitting the pads, fitting amplifiers on 2-wire terminal circuits having more

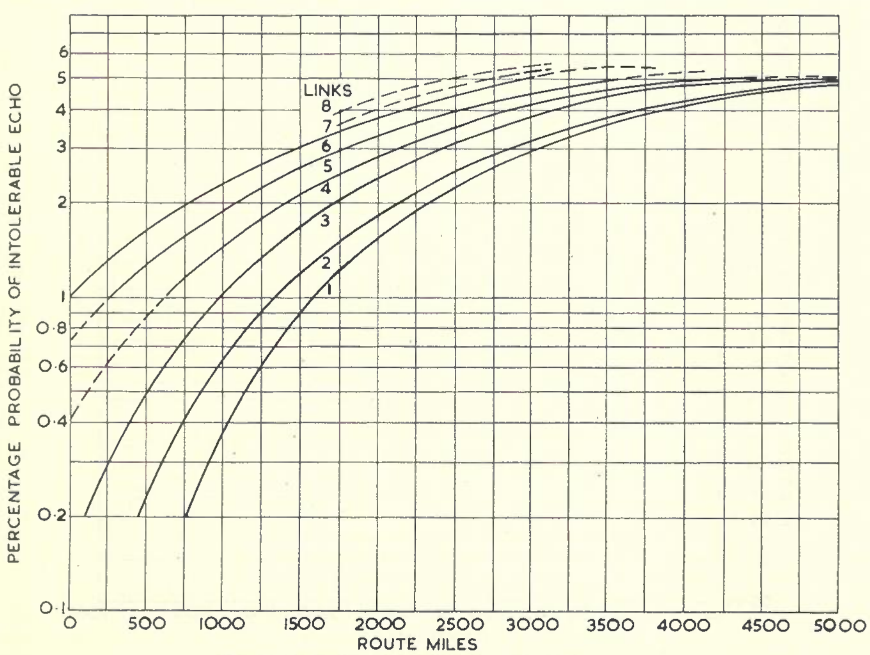

Fig. 14.—Echo Performance vs. Route Distance.

than 3dB passive loss, and increasing the loss of the 4-wire circuits by 7dB, compared with Fig. 15. It follows that under these circumstances the loss e in Fig. 15 will be that between 4-wire switches (Fig. 16b). There are some advantages in this method of operation, but it is likely that the arrangement of Fig. 16a will be adopted as the standard method for the Australian trunk network.

It is interesting to note that subsequent to the production of the design shown in Fig. 15, the C.C.I.T.T. has produced a report provisionally recommending the adoption of a 'step' formula comparable for all practical purposes, to that proposed in this article (10). It would add 1dB to the loss of the longer inter-state circuits and ½dB to some circuits longer than 1250 miles. Using the conventions of this article, the design appears to be based on a straight-line formula of (0.25 + 1.61D) dB — i.e., a lower "per-link" component and a higher gradient than derived here. The report also assumes with this article, that echo suppressors may be required on the longer links.

7. NETWORK LOSSES: FINAL CHOICE ROUTE

We now come to step (e) of paragraph 6: testing the design of Fig. 15 against international limits of circuit loss. The C.C.I.T.T. limits for the allowable loss between a subscriber's telephone and the international exchange in any country are at present 18.2dB (sending) and 13dB (receiving), and these include the sending and receiving equivalents respectively of the subscriber's telephone instrument, which in the Australian standard are 7.4dB and 3.6 dB respectively.

Subtracting these values from the allowances, we obtain a permissible limit of 10.8dB (sending) and 9.4dB (receiving) between a terminal exchange and the international exchange. Naturally, the lower of these values must control, and we round-off to find an allowable limit of 9.5 dB. Since the International Exchange for Australia is and will continue to be in Sydney, we have the limiting condition of 9.5dB between any terminal exchange in Australia and the Sydney International Exchange, which can be regarded as being connected to Sydney Main Trunk Centre by zero-loss lines.

Under the plan described in Fig. 15, it can be shown that the maximum-loss connexion between any terminal exchange and its Main Trunk Centre in each State is as follows:

N.S.W.	Vic.	Qld.	S.A.	W.A.	Tas.
8dB	8dB	9.5dB	8dB*	9dB	7.5dB

* Excludes Adelaide-Darwin; assume echo-suppressors.

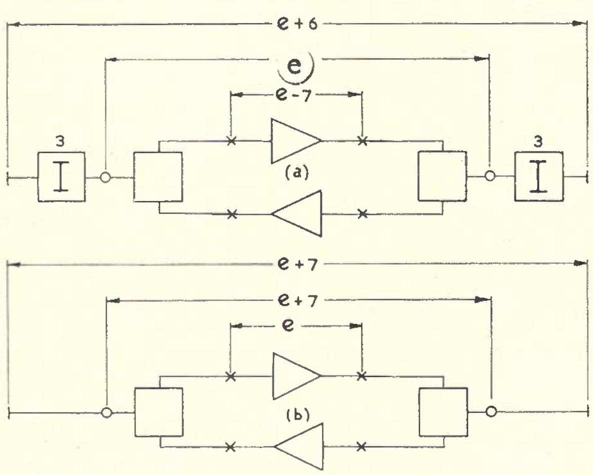

FIG. 16. (a) SUBSCRIBER-TO-SUBSCRIBER LOSS WHEN 'e' IS THE 2W-TO-2W LOSS AS SHOWN IN FIG. 15.
(b) SUBSCRIBER-TO-SUBSCRIBER LOSS WHEN 'e' OF FIG. 15 IS TAKEN AS THE 4W SWITCH-TO-4W SWITCH LOSS.

NOTES.
1. X X REPRESENT POSSIBLE 4W SWITCH CONTACTS. O REPRESENTS POSSIBLE 2W SWITCH CONTACTS.
2. SUBSCRIBERS ASSUMED TO BE IN SAME EXCHANGE AS TERMINATING SET.
3. LOSS THROUGH TERMINATING SET ASSUMED 3.5 db.
4. ARRANGEMENT OF FIG.16b REQUIRES AMPLIFIERS IN SOME 2W LINES TO TERMINAL EXCHANGES; THAT OF FIG. 16a GENERALLY REQUIRES NO AMPLIFIERS.

Fig. 16.—Subscriber-to-Subscriber Loss.

By subtracting the above figures from 9.5dB, we determine the maximum allowable loss between Main Trunk Centres and Sydney Main Trunk Centre. Similarly, by subtracting the sum of any pair of the above figures, excluding N.S.W., from 19dB, we obtain the maximum allowable loss between any two Main Trunk Centres, and derive the following table, in which the figures in brackets show the minimum attenuation from Fig. 15.

	Melbourne	Brisbane	Adelaide	Perth	Launceston
Sydney	1.5 (1)	0* (1.5)	1.5* (2)	0.5* (3.5)	2 (1.5)
Melbourne	—	1.5* (2)	3 (1)	2* (3)	3.5 (1)
Brisbane	—	—	1.5*(2.5)	0.5* (4.5)	2* (2.5)
Adelaide	—	—	—	2* (2.5)	3.5 (1.5)
Perth	—	—	—	—	2.5*(3.5)

Where the maximum loss is less than the (bracketed) minimum loss in the above table, echo-suppressors would have to be fitted to the circuits to enable the loss to be reduced without incurring troublesome echo effects; these routes are marked * above.

Ten routes (plus Adelaide-Darwin) are seen to require echo suppressors; of these, five are existing routes, and the remainder will be provided when the quantity of traffic justifies them. The method of including echo-suppressors is not yet finally determined; they may be fitted to individual circuits, or it is possible that they may be switched-in in the future subscriber-trunk-dialling network on certain destination codes. Certainly, individual circuit application would be required in the period before S.T.D. was introduced between States, and this implies large numbers of echo-suppressors on the major routes of those marked * in the above table.

Another factor so far not considered is that the C.C.I.T.T. limits from which the above figures are derived are absolute limits, and should include the variations in loss described in paragraph 4.2; these variations would tend to require reduction of the maximum losses shown in the above table. It will be seen too that the loss between the "worst" terminal exchanges in N.S.W. and the "worst" terminal exchange in any other State would be 17.5 dB; between any other States, the corresponding figure would be 19 dB. The present nominal loss limit between any two terminal exchanges is 15 dB.

In view of the above factors, it may be too precipitate a step to adopt immediately the plan of Fig. 15. and if a compromise must be made, it should perhaps be with respect to echo and stability (in which fields there is much difference of opinion), than with respect to internationally-agreed loss limits, which will have increasing importance to Australia with the completion of the Commonwealth Pacific Telephone Cable.

The compromise proposed, therefore, makes some concession towards the necessity to increase loss with distance to control echo effects, but not to the extent deemed desirable in Fig. 15. It is fortunate that any plan which may be adopted for the design losses on 4-wire trunk circuits is not irrevocable;

amendments can be made at any time in the future at negligible cost. Here, then, are the proposed transit-condition circuit losses for the Australian trunk network:

Interstate Main-to-Main:

0.5 dB except Sydney-Adelaide and Melbourne-Brisbane, which are 1 dB. Echo-suppressors to be fitted to all circuits terminating at Perth, and also to Adelaide-Darwin.

Intrastate:

0 to 350 miles: 0 dB
$>$ 350 to 750 miles: 0.5 dB
$>$ 750 miles: 1 dB

Experience with these values of loss will enable the echo problem to be assessed, and further adjustment made if found desirable. A vital feature of any transmission plan will be the machinery necessary to ensure that it is adhered to; we must be sure that when links of known nominal loss are switched in tandem, the actual overall loss is in fact the sum of their individual losses, taking into account the known sources of variation. Losses will therefore need to be specified between switchboard jacks or switch contacts, and the effects of relay sets, internal cabling, etc., accounted for in the overall circuit losses.

8. CONCLUSION

This article has examined problems of instability and echo in a 4-wire-switched, multi-link trunk network, and has deduced a design basis for the nominal circuit loss of all 4-wire trunk circuits. Many other problems remain to be discussed: the overall loss distribution between subscribers; losses on high-usage routes; the place of 2-wire switching in the trunk network; the special problem of minor trunk switching centres; impedance-correction methods for improving return loss at terminating sets; and the economic possibilities of redistribution of loss in the lower echelons of the trunk switching network.

The author is indebted to members of the Long Line Equipment Section, Headquarters, for some data and for valuable discussions, and to Mr. K. R. Collyer for his contribution to the analysis of echo conditions.

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APPENDIX I
RETURN LOSS

By definition, return loss is a measure of the degree of mismatch between two impedances Z_0 and Z_1. For our purposes, however, it is more illuminating to regard it as a measure of the proportion of incident power (at a junction of source and load impedances Z_0 and Z_1) which is returned to the source.

Fig. A1.1(a) shows a generator (1) with source impedance Z_0 and a load impedance Z_1 ($\neq Z_0$). The current flowing is $I_1 = E/(Z_0 + Z_1)$. This represents the general condition of an unmatched connexion.

What significance have these two fictitious currents? Firstly I_0 is the current which would flow if the load impedance equalled the source impedance Z_0. It may be regarded as a reference current. Secondly, the current I_x represents power sent back from the load to the generator (1). It produces reflected power. It is due to the generator $I_1 Z_x$; therefore, it is small when Z_x is small, vanishing to zero when $Z_1 = Z_0$, or $Z_x = 0$.

The ratio of the reflected current I_x to the reference current I_0 is known as the reflexion co-efficient; we shall derive it in terms of Z_0 and Z_1.

From Fig. A1.1(c),

$$I_x = \mp I_1 Z_x / 2Z_0 \quad \text{(A1)}$$

and $$I_1 = I_x + I_0 \quad \text{(A2)}$$

Then substituting for I_1 in (A1):

$$I_x = \mp (I_x + I_0) Z_x / 2Z_0$$

$$2Z_0 I_x = \mp Z_x I_x \mp Z_x I_0$$

$$I_x (2Z_0 \pm Z_x) = \mp Z_x I_0$$

$$\frac{I_x}{I_0} = \frac{\mp Z_x}{(2Z_0 \pm Z_x)} = \frac{\pm (Z_1 - Z_0)}{Z_1 + Z_0} \quad \text{(A3)}$$

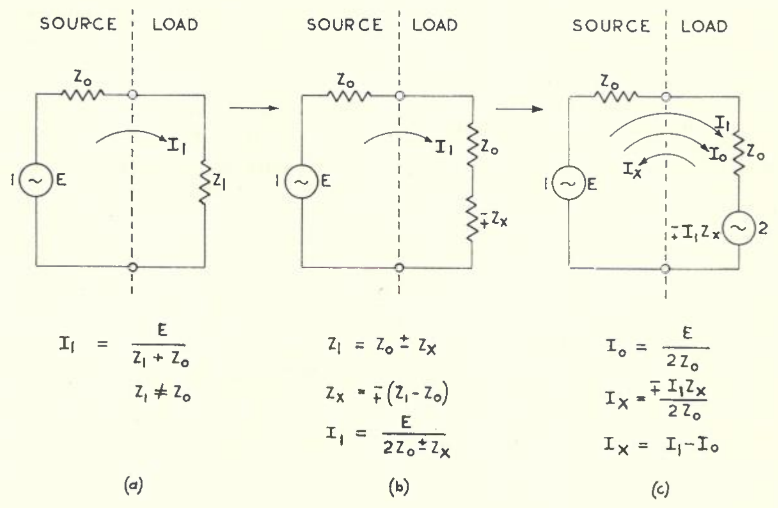

Fig. A1.1.—Return Loss.

Fig. A1.1(a) may be redrawn as Fig. A1.1(b), where we replace Z_1 by two impedances Z_0 and Z_x. If $Z_1 < Z_0$, then Z_x is negative; if $Z_1 > Z_0$, Z_x is positive.

Now the Compensation Theorem allows us to replace any impedance by a fictitious pure generator having an e.m.f. equal to the p.d. across it: applying the theorem to impedance Z_x, we arrive at the equivalent circuit of Fig. A1.1(c) in which $\pm Z_x$ is replaced by a pure generator (2) of e.m.f. $\mp I_1 Z_x / 2Z_0$.

The Superposition Theorem can now be applied. It tells us that the current flowing due to one or more generators (I_1, due to generators (1) and (2)) is the sum of the currents which would flow when each generator is shut down in turn. (I_0 flows when generator (2) is shut down, and I_x flows when generator (1) is shut down.)

The positive sign applies when $Z_1 > Z_0$, and the negative sign when $Z_1 < Z_0$. It must be borne in mind that the Z values will generally be complex numbers, and can involve reactances of either sign. Thus the radio I_x/I_0 is strictly specified only in terms of both magnitude and phase.

In echo studies, the phase of the returned current is immaterial; and it may be neglected also in stability studies, where many other uncontrollable phase changes occur in other components of the transmission circuit. We are principally interested, therefore, in the magnitude of the returned current. Since the reflexion coefficient is generally less than unity, and we would find a decibel representation more useful, we take the reciprocal of the current ratio, expressed as the modulus of the corresponding impedance ratio, convert it to decibels, and call it a "return loss":—

$$L = 20 \log_{10} | I_o/I_x |$$
$$= 20 \log_{10} \left\| \frac{Z_1 + Z_o}{Z_1 \sim Z_o} \right\| \text{dB}$$

When $Z_1 = Z_o$, then the denominator is zero, and the return loss is infinitely large.

Since the impedances Z_o and Z_1 are, in practice, complex quantities (i.e. they comprise both resistance and reactance) it follows that a given value of return loss can correspond to a range of values of Z_o and Z_1. It is convenient to express return loss in terms of the ratio $Z_1/Z_o = z \angle \theta$. To illustrate the order of variation of return loss with z, we give below selections from the range of $z \angle \theta$ corresponding to return losses of 10 dB and 20 dB.

Return loss	$z \angle \theta$	
10 dB	$1 \angle 35^\circ$	$1 \angle 35^\circ$
	$0.9 \angle 34^\circ$	$1.11 \angle 34^\circ$
	$0.8 \angle 33^\circ$	$1.25 \angle 33^\circ$
	$0.7 \angle 29^\circ$	$1.43 \angle 29^\circ$
	$0.6 \angle 21^\circ$	$1.67 \angle 21^\circ$
	$0.54 \angle 0^\circ$	$1.85 \angle 0^\circ$
20 dB	$1 \angle 11.5^\circ$	$1 \angle 11.5^\circ$
	$0.91 \angle 10^\circ$	$1.1 \angle 10^\circ$
	$0.86 \angle 75^\circ$	$1.16 \angle 7.5^\circ$
	$0.84 \angle 5.5^\circ$	$7.19 \angle 5.5^\circ$
	$0.82 \angle 0^\circ$	$1.22 \angle 0^\circ$

The above table clearly illustrates that for higher values of return loss, there must be close control of the angle of Z_1/Z_o as well as the magnitude.

For completeness, it is interesting to note that if the angle θ in $z \angle \theta$ lies between 90° and 180°, a return *gain* rather than a return loss, can occur. However this requires the angles of Z_o and Z_1 to be large and of opposite sign—a rare occurrence in the telephone network. For the particular cases of return loss against 600 ohms considered in this paper, the point is of only academic interest.

APPENDIX II
THE STATISTICAL APPROACH

General

There are many millions of possible combinations of links in a national telephone network. These combinations include short-distance calls with only a few links per call, and long-distance calls, with larger numbers of links. Ideally, it is the job of the engineer to ensure that every possible combination of links shall give a certain minimum satisfactory performance, in terms of speech quality, noise and loudness.

In practice, the achievement of this objective is difficult and unjustifiably expensive. A similar problem arises in automatic telephone exchange design: to ensure that every caller obtains immediate connexion would demand such large amounts of switching equipment that a less perfect solution must be sought. Accordingly, telephone exchanges are designed so that during the busy hour, a subscriber has (say) a 1 in 100 chance of not being able to make his call immediately. This allows significant economies in switching equipment, and at the same time provides negligible inconvenience to the subscribers.

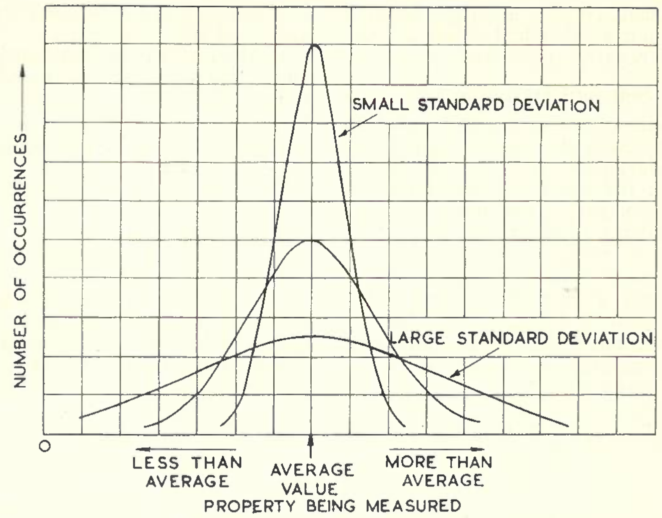

Fig. A2.1.—The Normal Law (1).

The equivalent action in the transmission field is to ensure that the average call provides a relatively high standard of transmission performance, that the vast majority of calls meet a lower, but still satisfactory, performance, and that the "unsatisfactory" call is a rarity. These qualitative objectives must be expressed numerically, of course, and this is discussed in the body of the article.

Our main assumptions in developing the statistical approach to transmission aspects of the national telephone service are that each variable element obeys a "normal" law, and that the effect of combinations of numbers of links obeys a "normal" law. With these assumptions, it is possible to add the average values and the standard deviations of the variable elements in a systematic way to produce a prediction of the behaviour of the whole system in terms of an average and a standard deviation value. Alternatively, the result may be expressed in terms of the percentage of connexions which meet given performance standards. The following paragraphs outline the meanings of "average", "standard deviation" and "normal law", and describe the methods of adding the effects of different variable elements.

Average

The circuit loss of a 4-wire telephone circuit is subject to variation with time. It will depend on the weather (if an open-wire system), temperature, the efficiency of gain-regulating devices, power-supply variations, etc. Suppose the circuit loss is measured every 2 hours during the day, and that the following table gives the results:

Hour	00	02	04	06	08	12	14	16	18	20	22
Circuit loss (dB)	–1	–1.5	–2	–2	–1	0	0.5	0	–0.5	–1	–1

The average value of the measurements over the day would simply be the sum of the values on the bottom line divided by the number of tests, $= -9.5/11 = -0.864$ dB. This tells us only a little of the behaviour of the circuit loss during the day: it tells nothing about the *amount of variation* which took place. The same average value could have been obtained if one of the

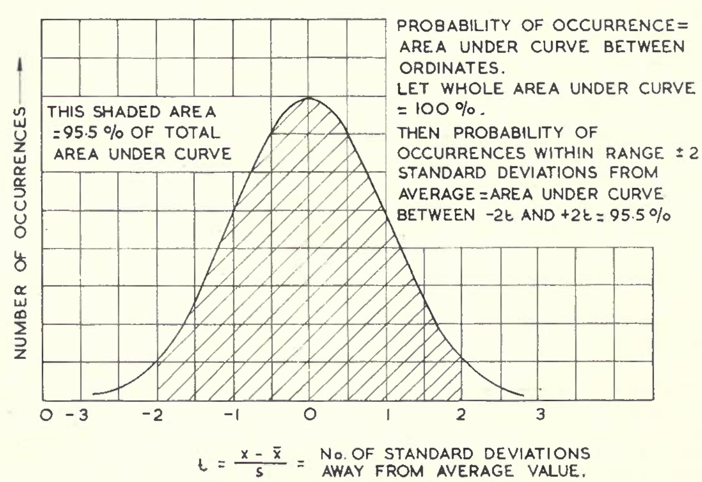

Fig. A2.2.—The Normal Law (2).

readings had shown a large positive deviation and another had shown a compensatory negative deviation.

Standard Deviation

A measure of the amount of variation is clearly required: this is called the standard deviation. This quantity is derived from the square of the difference between each reading and the average of all the readings. (The square allows both negative and positive deviations to be expressed as a positive number).

In symbols, if $\bar{x}$ is the average value of all the readings, if x_1, x_2, x_3, etc., are the first, second, third, etc. readings, and if n is the number of readings, then the standard deviation is:

$$s = \frac{\sqrt{(x_1 - \bar{x})^2 + (x_2 - \bar{x})^2 + (x_3 - \bar{x})^2 + \cdots (x_n - \bar{x})^2}}{n}$$

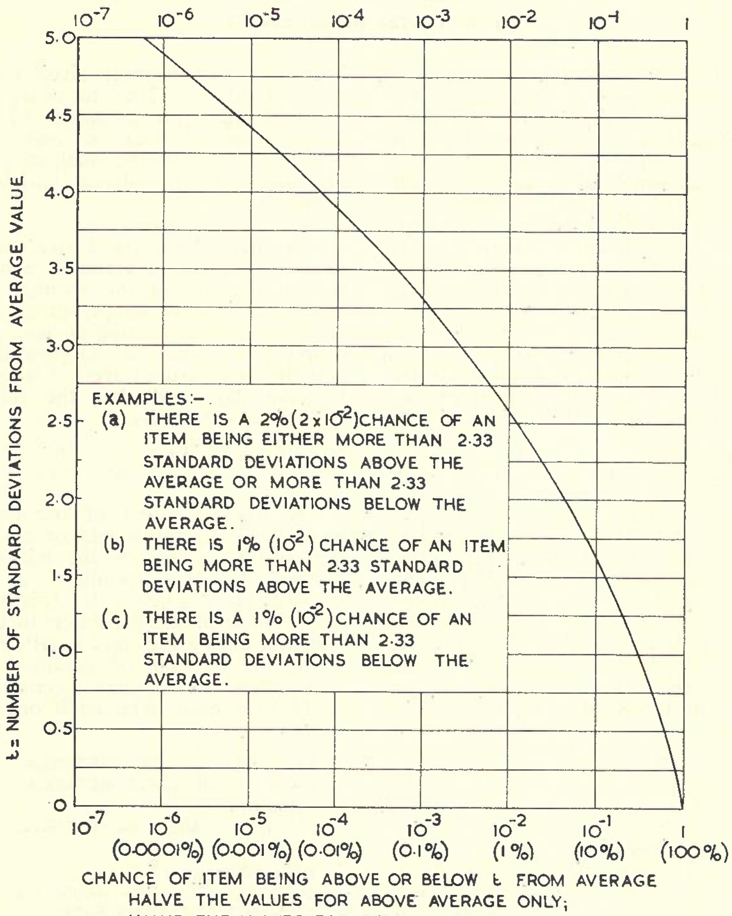

Fig. A2.3.—The Normal Law (3).

If there were no variation in the value of x, then each term in the numerator of this expression would be zero, and the standard deviation would also be zero.

If large variations (either above or below the average value) took place, the terms in the numerator would also be large, and would correspondingly increase the value of the standard deviation.

Thus we have a measure of the variability of our readings.

In the case of the two-hourly readings above, we work out the standard deviation:—

$$s = \frac{\sqrt{(-1 + 0.864)^2 + (-1.5 + 0.864)^2 + \cdots (-1 + 0.864)^2}}{11} \text{ dB}$$

and the result is:—

$s = 0.768$ dB

In the two numbers $x = -0.864$ dB and $s = 0.768$ dB we have a nearly complete description of the behavious of the circuit loss of the 4-wire circuit. If we can further assume (as is likely) that the variation obeys a Normal law, then the description is complete.

Normal Law

The Normal Law describes a mathematical relationship between the frequency of occurrence of an event, the average value $\bar{x}$ and the standard deviation s. It is a law which is found to describe many natural random phenomena.

By obtaining measurements on a relatively small number of people, for example, it is possible to assume a "normal" distribution and to deduce certain characteristics of the population as a whole. In this way, a boot manufacturer can estimate the likely range of sizes and quantities of each size of boots for issue to an army; a schoolmaster can anticipate the proportion of "bright" and "dull" pupils in relation to those classed as "average"; and a telephone manufacturer can design the mouthpiece-to-earpiece distance of a handset to have minimum transmission impairment (for talkers with a small mouth-to-ear distance) and minimum inconvenience (to users with a large mouth-to-ear distance (11).

The law is illustrated in Fig. A2.1 and shows that the average value occurs most frequently in a given set of observations. A large standard deviation implies a wide spread of values about the average; the average value occurs less frequently than before. A small standard deviation implies a narrow spread of values about the average; the average value occurs more frequently.

The curve is symmetrical; an occurrence of two units greater than the average is just as frequent as one two units below average. Furthermore, the curves never reach zero on the "percentage of occurrences" scale: there is a very small, but finite frequency of occurrence for even very large deviations from the average value.

It is clear from the above that the Normal Law is a mathematical fiction which cannot be expected to "fit" all variable events; the latter may be limited by certain boundary conditions which do not agree with the Normal Law for very small percentages of occurrence.

However, for all practical purposes, the errors are either negligible, or can be allowed for, and are greatly outweighed by the convenience of being able to account for variations in a systematic and calculable manner.

It is usually convenient to express the Normal Law not in the dimensions of the quantity under examination such as in Fig. A2.1, but in a dimensionless quantity t, where $t = (x - \bar{x})/s$; x being the quantity under examination, $\bar{x}$ its average value and s its standard deviation, both in the same units. In effect this measures a departure from the average as a number of standard deviations.

If the curve of Fig. A2.2 represents a distribution under this "normalized" rule, it can be shown that the probability of an item lying between two values of t is proportional to the area under the curve, bounded by the vertical lines at these two values. The area under the whole curve is unity, representing a 100% "chance" of encountering all values of t. In particular, there is a 68% chance of an item being found within ± t (± 1 standard deviations), 95.5% chance of it being within ± 2t (±2 standard deviations) and 99.74% chance of it being within ±3t (±3 standard deviations).

Fig. A2.3 shows the chance of items lying *outside* given values of t in the range t = 0 to t = 5.

Application

If we can assume that all the variations in our transmission problem follow a Normal Law, then we can express their total effect in terms of their individual averages and standard deviations: the result will still be a distribution with a Normal Law, having an average value equal to the arithmetic sum of the individual averages and a standard deviation equal to the r.m.s. sum of the individual standard deviations. From this single result, it is then possible to determine the chance of a given variation being exceeded by the random effect of all the variables operating collectively. Alternatively, it is possible to fix the nominal value of one of the elements in the problem to ensure that there is only an assigned small probability that a given criterion is exceeded.

Is the primary assumption valid? There seems to be sufficient evidence to support it with respect to variation of return loss, subscribers' line loss, circuit loss with time, and subscribers' tolerance to echo. The case may not be so strong with respect to circuit loss variation with frequency, but the effect of errors here is believed to be small.

APPENDIX III
CLASSIFICATION OF SWITCHING CENTRES

Switching centres must be classified so that tandem connexions are made in a systematic manner. This ensures that the design maximum for the number of links which may be connected in tandem, imposed by switching and transmission considerations, will never be exceeded. It also enables the permissible transmission losses to be assigned to individual routes so that satisfactory performance can be given on multi-link connexions.

In Australia, with its great distances and particular distribution of population, five classes of switching centre are used in order to take the fullest advantage of an automatic switching system using alternate routing. The centres are classified according to their position in the final route pattern with respect to centres of lesser order. The classification applies to all exchanges, whether located in metropolitan or country networks, and has no relationship to the number of subscribers' lines connected.

The classifications of switching centres are defined thus:—

A Terminal Exchange is an exchange which performs no through-switching of inter-exchange circuits.

A Minor Switching Centre switches the final routes for Terminal exchanges only.

A Secondary Switching Centre switches the final routes for Minor switching centres and also, if required, Terminal exchanges.

A Primary Switching Centre switches the final routes for Secondary switching centres and also, if required, Minor switching centres and Terminal exchanges.

A Main Switching Centre switches the final routes for Primary switching centres and also, if required, Secondary switching centres, Minor switching centres and Terminal exchanges.

In referring to the final route connection of an exchange, through its parent switching centre, to the Main switching centre, the term "Final Route Chain" or 'Final Chain" is used.

LETTER TO EDITORS

THE CASE FOR A "4-WIRE" SUBSCRIBER'S LINE

Engineering Division,
Postmaster-General's
Department, Sydney.

Sirs: If we examine the various links which make up a telephone communication connection, we become aware that the greatest proportion, at least of the long distance connections are "4-wire" in nature. The telephone instrument, for example, is a "4-wire" device, consisting of a separate transmitter and receiver joined together through the arms of a hybrid coil. The junction lines connecting exchanges in a multi-exchange network are largely "2-wire" at present, but the modern tendency is to convert these to "4-wire" operation in conjunction with the application of new systems of switching and because the cost of the carrier equipment is becoming competitive with cable for shorter distances. Trunk lines are mostly "4-wire" in nature, either physical, carrier or radio. International circuits are wholly "4-wire" and radio international circuits now in operation will be largely supplemented by carrier in cable in the near future.

There is a tendency in cases where the links consist of "2-wire" VF cable circuits, to concentrate all allowable losses in these "2-wire" circuits and to curtail costs by saving copper to the point where transmission and loop resistance limits are exceeded. The question arises, "Should we consider a '4-wire' circuit throughout from telephone set to telephone set, precipitating the use of carrier equipment, facilitating the use of amplification without instability and removing tendencies to degrade transmission efficiency to save capital expenditure?" The following are some of the advantages it is felt would accrue if such a system were introduced:—

(1) All hybrid coils would be eliminated including those in the telephone sets, adding greatly to the stability of communication links and freeing the long distance circuits of all echo effects.

(2) The elimination of the carbon transmitter, which represents a maintenance problem by replacing it with a magnetic or crystal transmitter, sufficient gain being provided in the circuit to compensate for lower efficiency. In a "4-wire" circuit this gain can be readily added without risk of instability.

(3) Subscribers cable circuit limits of loop resistance can be extended to 2,000 ohms if "4-wire" (2 band) equipment of a type recently tested is applied.

(4) The overall transmission conditions can be substantially improved and made to simulate more nearly the perfect communication system (vide the design of speech communication systems, Ref. 1).

(5) Echoes on long distance calls, which will in the near future be extended to "4-wire" submarine cable connections to New Zealand, Canada and Europe, can be eliminated or very substantially reduced.

(6) The general noise level in subscribers and junction cables will be reduced by the introduction of "4-wire" circuits because the carrier and VF amplified circuits used would be equipped with tone signalling which is not as noisy as the DC pulses transmitted in D.C. signalling.

(7) If a "4-wire" subscribers line of the 2 band form (carrier reception, voice transmission) is introduced, near end crosstalk in subscribers cables will be brought under control. At the present time a crosstalk limit has been reached with the more efficient telephones because of the large difference between sending and receiving levels.

(8) The simplification of relay set circuits required with "2-wire" lines can be effected when "4-wire" lines are introduced.

The telecommunication network was originally established in the form of open wire construction with short rubber covered leads at the ends. As the towns and cities grew in size, it became necessary for these wires to be underground and long lengths of heavy conductor, paper insulated cables were installed as "lead in" cables to the towns and cities. The length of cable allowed was regulated by the ability to conduct a telephone communication, and the interconnexion of remote areas, between States, or to overseas countries was not envisaged, and no overall transmission plan existed. Very heavy gauge copper wires were erected in some cases in a rather futile attempt to improve or preserve transmission conditions.

The introduction of the thermionic valve repeater and the carrier system on open wires brought with it the realisation that a communication system extending throughout the Commonwealth was practicable. Carrier equipment was rapidly applied to by-pass the physical line circuits, and a telephone transmission standard for application to the Australian Network became immediately necessary. A tentative transmission scheme

(Laboratory Report 18) was developed and issued on 11.8.1927. The longest connection allowable under this scheme, however, actually exceeded the recognised limit of commercial speech, with good speakers' voices, quiet lines and quiet acoustic conditions. A revision of this scheme took place later, and the first standard was prepared and issued on 25.6.1934 (Drawing C.1054) based, it is understood, on the equivalent of acoustic free space transmission of one metre of air, but with no allowance for noise, echo and distortion in the long distance communication system. The standard covered merely the conditions of two subscribers services connected together by a noiseless, distortionless and echo free trunk line connection. A later standard incorporated in Planning Instruction, B.2050 and shown in figure 1 of that Instruction, issued on 1st January, 1957, shows an allowance of sixty phons of acoustic noise at the telephones, but still no allowance for the noise, distortion and echo conditions which are inherent in the "2-wire" amplified portions of the trunk system.

For many years, circuits have been provided on the basis of this transmission standard and have been largely in the form of physical cable circuits, because these had been the most economical type of circuit available at that time, and efforts have been made to meet the requirements of this transmission standard by absorbing half the total allowable losses for the connection between exchanges, in the junction network. Inductive loading has been introduced to extend the use of these cables to the limit, but because the cost of cable installations is almost directly proportional to the length of the installation there has always been a strong tendency to exceed transmission limits because of the substantial savings in capital cost which can be made by so doing. In fact, a number of junction cable proposals have been approved on the basis that amplification will be provided at a later date to compensate for the excess losses. Subscribers cables have also been allowed to exceed the transmission limits on the basis that improved telephones which are becoming available, will be applied to these cables.

A review of the transmission conditions in a large multi-exchange network like Sydney shows that conditions are not satisfactory and that unless firm preventive action is taken, transmission conditions will continue to be degraded. To face the realities of the future we should seriously consider reducing the 15 db allowance between any two exchanges to say, 10 db or less to compensate for noise, distortion and echo, which are inherent in any system which employs "2-wire" circuits wholly or partly in its construction. This reduction in allowable loss which could not be achieved without the introduction of stabilising and echo suppressing measures, immediately changes the picture with regard to the provision of junctions in the metropolitan exchange networks, and dictates the provision of a large number of "4-wire" circuits which can be more economically provided by carrier than by physical construction. The outlook then becomes so much more favourable towards the application of a *"4-wire" circuit throughout,* that the suggestion to apply "4-wire" operation, which will eliminate echo on long distance circuits, is both attractive and timely.

The process of "by-passing" the physical line construction which has been applied largely in country districts should be applied in the metropolitan cable networks and facilitate the provision of long distance echoless connections for the bulk of long distance trunk users as early as possible. Not only will a decision to improve transmission standards, more closely aligning them with the perfect system, precipitate the greater use of carrier for junctions, but the greater use of carrier in turn will affect prices and economic considerations of the application of a "4-wire" system so that the introduction of carrier will tend to accelerate beyond the rate now envisaged.

It has been stated that articulation approaching the ideal conditions is obtained when two intelligent people with normal hearing are speaking in loud, clear tones in an absolutely quiet room free from reflecting surfaces and facing each other at a distance of one metre (See Ref. 1). The aim of a communication network of the future, no doubt, will be to approach the condition of the perfect system as nearly as the resources available will allow. It seems to be quite patent that these conditions could not be approached very closely if any "2-wire" section of line were left in the circuit during conversation over long distances. The limit of 15 db between exchanges has not been applied successfully and with "2-wire" circuits there is not much chance of this being possible.

Accepting that a complete "4-wire" system is necessary, and considering the problems of introducing such a system, a few notes have been prepared on its application. The conversion of a junction line system to "4-wire" operation could be greatly facilitated by a programme of installation of coaxial cables or other wide band bearers along the main junction routes in conjunction with the provision of similar circuits for television purposes. The introduction of 120 channel (double super group) carrier systems on selected cable pairs with intermediate repeaters of the transistor type would also help. With the introduction of common control switching systems and the establishment of tandem switching centres in the larger multi-exchange networks, decentralisation of the trunk centres can be carried out to a considerable degree by providing direct groups of trunks between large exchanges external to the network and the tandem switching centres within the network, discriminating facilities being provided to enable the main trunk centre to be by-passed. This would result in the saving of expensive channel terminating and automatic switching equipment at the trunk centre. For example, groups of trunk lines could be provided directly from Wollongong to, say Newtown or from Melbourne to, say, Newtown or Ashfield, etc., the only equipment being required at the trunk centre being group or super group modulating equipment. The installation of coaxial cables would also have the following advantages:—

(1) The life of the existing tunnels would be extended and
(2) Junction and trunk equipment would be provided simultaneously with each exchange extension. The provision of junction equipment would be spread more evenly over each planning period.

A "4-wire" telephone has been manufactured and set up for trial purposes. The oscillator, which could be made capable of supplying an 8,000 cycle carrier to all subscribers' services was set up in the exchange and connected to the modulation equipment provided to transmit the telephone conversation to the telephone set in the form of a lower side band of 8kc/s. A simple detector was provided in the telephone which converted this to voice frequency. In the sending direction from the telephone the normal voice frequencies were used, but the dial in the "Off Normal" condition set up a tone signalling circuit which sent impulses to a suitable detector located at the exchange end on the line. The carbon transmitter is replaced by a receiver capsule which is used as an electro-magnetic microphone, and sufficient gains are provided with transistor amplifers to reduce the loss in the subscriber's line to zero in both directions, when a 10 lb. cable pair of 2,000 ohms resistance is used. The application of such a system to the Australian network could best be applied gradually at the country ends where small exchanges exist which are most likely to encounter transmission difficulties including echo. By providing the small number of "4-wire" type telephones required, all echo paths could be eliminated in a complete exchange.

It is not claimed that all the advantages or disadvantages of a complete "4-wire" scheme can be dealt with in a short letter of this type, but it is felt that so much good can accrue from the timely consideration of this problem in the light of the development of transistor equipment, the wide band bearer and the flexibility provided by register type of common control switching systems, that it would be a pity to let the great opportunity which is now offering, pass without giving earnest consideration to the provision of a "4-wire" telephone and complete "4-wire" conditions on all long distance telephone communication connections.—Yours, etc.,

A. H. LITTLE

Ref. 1: Proc. I.R.E., Vol. 35, No. 9, Sept. 1947.

THE APPLICATION OF GAS PRESSURE ALARM SYSTEMS TO COAXIAL CABLES

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INTRODUCTION

The constant pressure gas alarm (G.P.A.) system has now been in use in Australia for a number of years. Briefly the system consists of making a cable network gas tight by eliminating as many leaks as possible, and then installing contactors at regular intervals to short circuit alarm pairs when the gas pressure drops to a predetermined value. This system has considerably improved the quality of trunk and junction service due to the detection of sheath failures before actual service interruption occurs. There is a saving in the cost of repairs in most instances. However, this has only been achieved at a comparatively large expense due to the need for making and keeping the sheath of a cable maintained under continuous gas pressure more "gas-tight" than would be necessary in those cases where a G.P.A. system was not installed.

With the introduction of coaxial cables in Australia the opportunity has been taken to review from first principles the facilities required of a G.P.A. system for coaxial cables. The necessary characteristics of a system, and which of the available systems is to be preferred, will then follow. As the use of long coaxial cables for trunk purposes has only recently been introduced into Australia, only limited practical experience in the operation of gas pressure alarm systems on this type of cable has been obtained. Most of the information available has, therefore, been obtained from overseas literature and an examination of systems purchased for field trials.

NEED FOR A SYSTEM

Even though the installation of a gas pressure alarm system may be costly, a reliable system is necessary to reduce interruptions to service due to sheath failure. In recent years the public have been given an increasingly reliable trunk line service, and have now come to expect it; therefore every possible step should be taken to ensure an uninterrupted service when a sheath failure occurs. With improving techniques it is now practicable to provide an inexpensive G.P.A. system that will give the desired facilities.

Further, as the make-up of coaxial cables is such that generally resistance to the passage of water along the cable is comparatively small as compared with quad cable, it is essential to ensure that water is prevented from entering the cable on sheath failure. Otherwise it will be found that cases will occur where the replacement of a considerable length of cable will be necessary due to water entry. This will not only delay restoration of service, but add considerably to the costs involved.

PNEUMATIC RESISTANCE OF COAXIAL CABLE

Coaxial cables generally have low pneumatic resistance to the flow of gas and water along the cable, the exact value depending mainly on the make-up of the coaxial cable, the make-up of the coaxial tubes; and the tightness of fit of the lead sheath on the cable.

Dry air, dry nitrogen and other dry inert gases are used in G.P.A. systems. In Australia, dry air is the standard. In this paper the terms "air" and "gas" are used interchangeably.

Average pneumatic resistance values for coaxial cable have been given as between 10% and 30% of that for 24/40 P.I.Q.C. cable, the actual value of any cable being determined by test. The low pneumatic resistance of coaxial cable is of first importance when considering a suitable gas pressure system. Since the air flow under a given pressure gradient will be high when compared with quad cables, the air present in a sealed system is soon lost from the cable thereby leaving it exposed to water entry. At the same time the low pneumatic resistance makes possible the use of continuous air flow systems in which air is fed into the cable as required from all or some of the repeater stations.

AIR FLOW IN CABLES

After a steady state is reached the volume of air flowing in a cable is determined by:—

$$\text{Air Flow} = \frac{P_2 - P_1}{\text{pneumatic resistance of cable length}}$$

where $P_2 - P_1$ is the pressure difference over the length of cable in question.

The unit of pneumatic resistance has been defined by the American Telephone & Telegraph Co. as follows: A unit of pneumatic resistance is the resistance offered to the steady flow of gas by 1,000 feet of cable of unit cross-sectional area (one inch diameter inside the sheath) and of such core structure that the steady rate of gas flow through it will be one cubic foot (at atmospheric pressure) per hour for each pound of admission pressure.

The pressure gradient in the cable depends on the resistance to air flow through the hole in the sheath, i.e., a function of the size of the hole and the

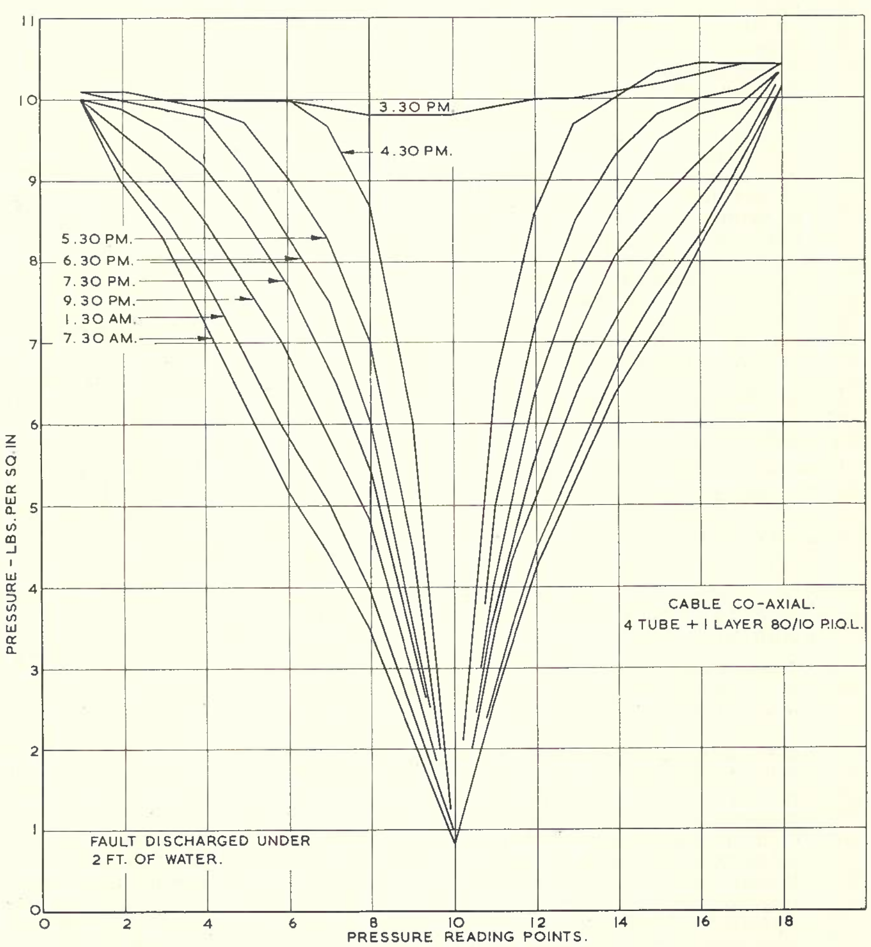

Fig. 1.

* See page 80.

surrounding pressures. In closely examining gas flow characteristics it is convenient to consider the effect of three separate classes of sheath failures as follows:—

(i) **Minute cracks, pin holes, porous wipes.** The resistance to flow through the hole will be considerable, reducing the pressure gradation in the cable to a small value and therefore the air flow as well. By correcting pressures measured at points along the cable for atmospheric temperature and pressure it may be possible to establish a pressure gradient, but not with any great accuracy.

(ii) **Small Holes**. In this case a positive pressure will exist in the cable at the site of the fault due to the resistance to air flow through the hole in the sheath. Fig. 1 shows pressure readings due to a simulated fault on a dummy repeater section of 4-tube coaxial cable with one 80/10 P.I.Q.L. layer. In the test seventeen 500 yard drums were connected together by rubber tubing and an artificial leak approximately 7/64 in. diameter was made near the centre of the section by removing a valve holder core. The fault was placed under two feet of water. Cylinders of air were connected at each end with regulators set at 10 lb. per sq. in. and the pressure was read at the junction between each consecutive drum. The air flow at each end of the test section was measured after the steady flow had become established and was 1.26 c. ft./hr. This type of system, where a reservoir of gas held at constant pressure, is permanently connected to the cable and automatically replenishes any leakage losses, is known as a **Continuous Flow System;** the alternative is the **Sealed System** where there is no supply of gas external to the cable and losses are not automatically made good.

Using this value of 1.26 c. ft./hr., the pneumatic resistance for this cable was determined from—

$$\text{Pneumatic resistance \textbf{per yard}} = \frac{\text{Pressure gradient}}{\text{air flow} \times \text{length}} = \frac{(10 - 0.9)\ \text{lb. per sq. in.}}{1.26\ \text{c. ft./hr.} \times 4{,}556\ \text{yards}} = 0.0016\ \text{units.}$$

(iii) **Large Holes.** Fig. 2 shows pressure readings for an artificial fault made in the centre of a repeater section of coaxial cable. The fault was made by removing a valve holder from the sheath leaving a hole about ¼ in. diameter. The hole was open direct to the atmosphere and the air pressure at the fault was zero. When the steady state was reached, the gas flow had increased to 1.464 c. ft/hour from each end of the cable due to the increase in the pressure gradient.

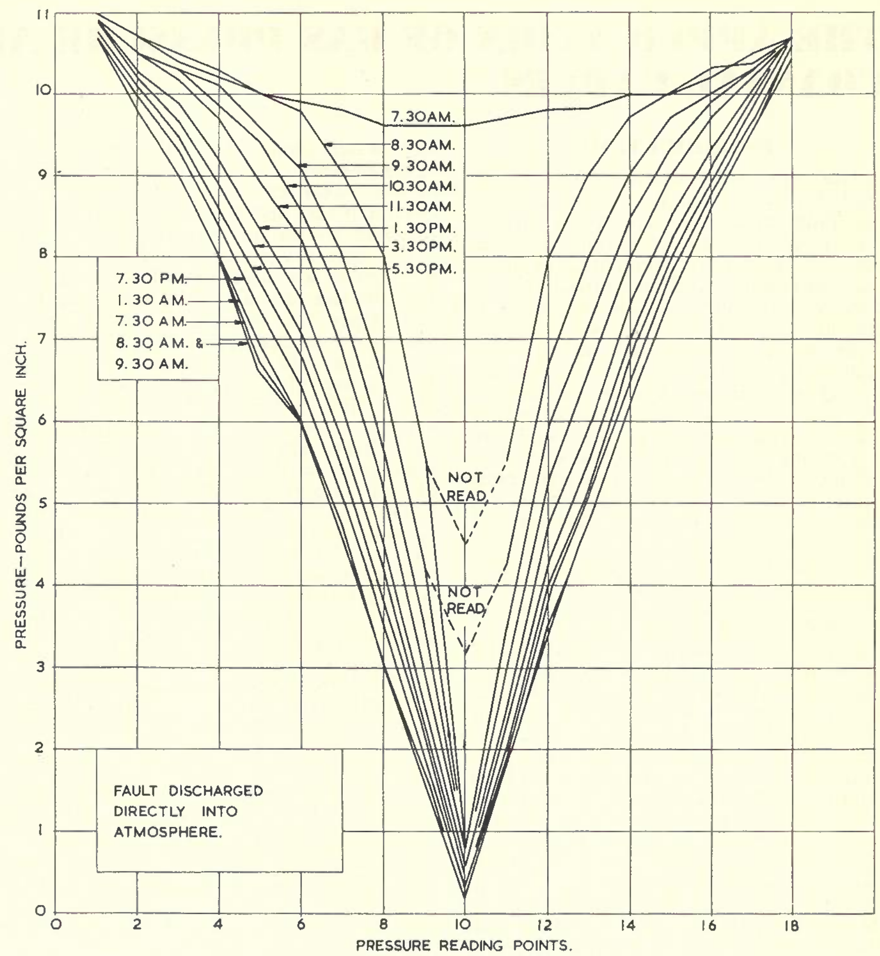

Fig. 2.

$$\text{Air Flow} = \frac{10.7 - 0}{.0016 \times 4{,}556}\ \text{c. ft/hour}$$
$$= 1.464\ \text{c. ft/hour from each end.}$$

Variation in Air Flow with Time. The protection a gas pressure system is capable of giving to a cable can be gauged by the air flow at the break in the sheath. Using the pressure gradient in Fig. 2, the volume of air flowing at the leak from the time the fault first developed until the steady state was reached can be determined. These flows are graphed against time in Fig. 3.

This curve shows how the air flow is at a maximum when the leak first develops and then diminishes until the steady state condition is reached. The values of air flow given in the graph were obtained over 4,556 yards of cable, the flow being measured from one end only. In practice, with air flowing from repeater stations on each side of the leak, the flows obtained would be twice the values given in the graph.

Air Flow in Sealed Systems. It is of interest to examine the behaviour of a sealed system under similar fault conditions as in Fig. 2. Fig. 4 shows the recorded pressure gradients in an English coaxial cable (reference 1). The cable under consideration was sealed at each end and no auxiliary air reservoirs were connected. A large hole was made in the centre of a length of 5½ miles. The air flow from the leak would be similar to that shown in Fig. 3 for the continuous flow system but instead of the flow stabilising it would continue to diminish as the pressure at the cable ends fell below 10 lb. per sq. in. The continuous flow system would give greater protection in the case of a hole midway between two repeater stations after a time lapse of about 5 hours.

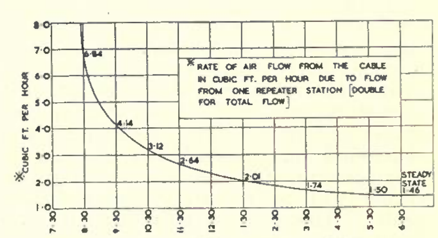

Fig. .3

Air Flow Variations with Leak Location. The cases cited so far have involved leaks at the midpoints of repeater stations with an air supply at constant pressure P_2 at each end of the repeater

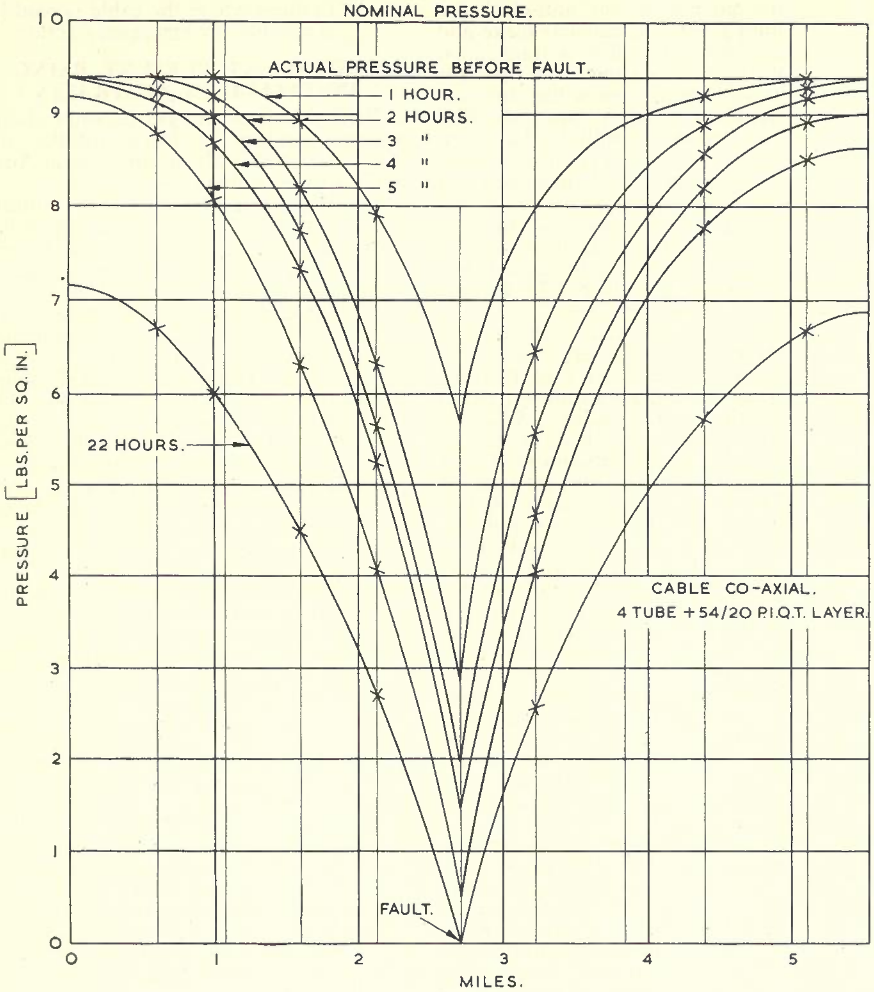

Fig. 4.

section. The air flow from the cable under this condition is:—

$$\text{Air Flow} = \frac{2(P_2 - P_1)}{R_p \times a/2}$$

The general expression for air flow at any point of the cable becomes:—

$$\text{Air Flow} = \frac{P_2 - P_1}{R_p \times x} + \frac{P_2 - P_1}{R_p \times (a - x)}$$

where "a" is the total length of the section in yards.

"x" is the distance of the fault from one end in yards.

R_p is the pneumatic resistance/yard of cable.

Assuming a constant pressure of 10 lb. per sq. in. is maintained at the repeater stations, the steady state air flow from a large leak in the cable would vary with location as in Fig. 5 where a repeater spacing of 8,000 yards is assumed. In the calculations the pressure at the fault was assumed to be zero and a value of 0.0016 units of pneumatic resistance per yard was used.

This curve illustrates the superior air flow achieved in the continuous flow system for leaks occurring near the air supply. If a leak occurred at a repeater station on a sealed system the air flow from the leak would initially be half that of a mid-section fault and would continue to fall as the pressure gradient in the cable diminished. For a similar leak in a continuous flow system, the air flow would be controlled only by the size of the hole in the cable, the pneumatic resistance of the cable being negligible.

Effectiveness of a Given Air Flow. The relationship between volume of air flow and the protection that it affords to the cable is of considerable importance in assessing the value of any form of gas pressure system. The first stage in the design of a system is to determine the gas flow required to keep moisture from a cable with varying sizes and types of sheath holes. Past experience of cable failures provides information on the likely type of hole that will be encountered and the requisite gas flow can be related to it. The gas pressure system must then be designed to ensure that this volume of air flow will in fact be obtained at the leak. Tests were conducted on a section of the Melbourne-Morwell coaxial cable after laying was completed to determine the limits of effectiveness of the continuous flow system installed on that cable. In the middle of a six mile repeater section, the coaxial cable was connected to a sealed paper insulated lead covered cable immersed in three feet of water. A 7/64 inch hole was made in the upper surface of the paper insulated cable and air flowed from the two repeater stations through the coaxial cable to the fault. The air flow from the fault of 3.0 c. ft/hour in the steady state was adequate to keep moisture out for 28 hours, the period of the test. The experiment was repeated for a ¼ in. hole under three feet of water and this time the insulation resistance of the cable dropped to 10,000 ohms after 1½ hours. Contactors located 1,000 yards on each side of the fault and set at 7.5 lbs. operated after two hours.

SOME TYPES OF G.P.A. SYSTEMS IN USE OVERSEAS

The three requirements of a system are:—

Provide an alarm on sheath failure.

In general prevent the entry of water until repairs can be effected. This is not possible if there is a water pressure at the leak in excess of the gas pressure.

Provide a means of locating the leak.

Brief descriptions of some actual systems at present in use on coaxial cables overseas are listed below, with a criticism of each. Appendix 1 gives the methods used for the location of the three basic types of leaks.

(i) **Sealed System with Contactors at 1,000 Yard Intervals.** This system is one used in Germany. Small mercury U-tube manometers are inserted inside the joints in the cable and are spaced at intervals of 1,000 yards. It is claimed that the operating point of these manometers (contactors) can be set with a very high degree of accuracy and that maintenance after the initial setting is not necessary. A quad in the cable is required for alarm purposes, the adjacent manometers being connected alternately across either pair 1 or pair 2. Each manometer has a distinct identifying resistance which is connected across the alarm pair when the manometer operates.

An automatic supervision set is located at a main or control station and provision is made for the connection of four alarm quads in four separate cables. When a cable fault occurs, one manometer operates and a line

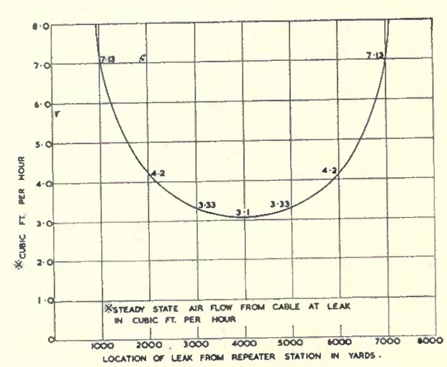

Fig. 5.

finder in the supervision set locates the pair containing the operated manometer. A self balancing wheatstone bridge is then connected to this pair, and the resistance associated with the operated contactor identified by switching into the bridge similar resistances to those associated with the manometers until the bridge is balanced. The number of the alarm circuit and the number of the operated manometer are then displayed in a panel, and the actual geographical position of the manometer is obtained by reference to a table. Further access to this circuit by the line finder is then blocked.

As air continues to escape from the cable the first manometer on the other side of the fault will be the next to operate, and its position can then be located by the supervision set in a similar manner. As this manometer is connected across a different pair, the operation of the first manometer will not interfere with the location of the second one. The fault is therefore isolated to within a 1,000 yard section of the cable and is finally located by visual inspection and the application of freon.

The success of this system relies on the correct functioning of the manometer and the efficient working of the supervision set. Gas is manually supplied to the cable at main stations to replace losses by normal leakage, but provision is also made to admit gas manually at any repeater station if required.

(ii) **"Automatic Gas Control" method (ref. 2, 3 and 4) on Continuous Flow Systems.** This system was developed in Sweden and it is understood to have given satisfactory service for some years. A gas cylinder is permanently located in each station and the supply of gas is permanently connected to the cable. Regulators maintain this gas at a constant pressure and gas is automatically fed to the cable as required to replace that lost by normal leakage or due to a fault. The function of the signal manometer (or pressure contactor gauge as it is known in Australia) is to indicate the quantity of air being fed into the cable.

The manometer does not give a continuous reading or indication of the rate of gas flow into the cables, but sends a signal at regular intervals as the pressure of gas in the cylinder is reduced. This is done by placing one contact of an alarm pair on the pointer of the manometer and the other one on a ratchet wheel in the manometer. Each signal manometer in a repeater or terminal station is connected to a register at a main or control station via two separate wires of a common quad in the cable. As the pressure of gas in the cylinder drops, the pointer moves anti-clockwise until finally the contacts make and an alarm or pulse is transmitted to the main station. The operator at this station notes the time the signal is received and identifies the station transmitting the alarm. After the pulse is recorded on the counter, the signal manometer of the repeater station is automatically reset and prepared to send another pulse. This pulse is sent when the pressure in the cylinder drops by a further 3.75 kg/cm^2 (53.3 lb. per sq. in.).

When a fault occurs between two stations, air is fed into the section from each end so that the two signal manometers transmit pulses to the main station. When a steady state is reached, i.e. the intervals of time between receipt of successive pulses from each station have stabilised for each station, location of the fault can proceed. The distance to the fault from the ends of the section is then given by the inverse ratio of the rates of flow or time intervals, and it is claimed that an accuracy of $\pm$ 2% is possible under all conditions, i.e., for large and small leaks. To obtain this high degree of accuracy, it is necessary that the signal manometers be accurate and that the pneumatic resistance of the cable throughout a repeater section be approximately the same.

It should be noted that an accuracy of $\pm$ 2% of a gas section, approximately 6 miles in length, is just over $\pm$ 200 yards which is less than a drum length. Final location of the fault is by the use of radon or freon. This system does not give early advice of a fault and some hours will elapse before approximate location of the fault can be made.

This particular system is the one installed on the Melbourne-Morwell coaxial cable, but a later design incorporates a means of measuring the change in the instantaneous rate of air flow when a leak occurs (Ref. 5). This should overcome the objection of the time delay in making an initial location of the position of a fault.

(iii) **Sealed System with Contactor Gauges at Repeater Stations.** This is the present British Post Office standard and uses a sealed system with contactor gauges located at terminal and repeater stations. Contactors were installed in earlier trials (apparently with a spacing of ¼ mile), but are not used at present because it is considered that contactors with the high degree of accuracy required are not readily obtainable.

Test valves are spaced on the cable sheath at intervals of 1,000 yards to enable pressure readings and pressure gradients to be obtained. Final location of a fault is by visual examination or the application of freon. However, it must be borne in mind that this scheme applies to cables generally in ducts where the cable is readily accessible for emergency action.

SYSTEMS AT PRESENT BEING INSTALLED IN AUSTRALIA

Brief details of the gas pressure alarm systems installed or being installed on current coaxial cable installations in Australia are as follows:—

(i) **Melbourne-Morwell** (120 miles). An Ericsson system has been installed on this cable, the alarms or pulses from the signal manometers being extended over two cable pairs to indicating receivers at either Melbourne, Dandenong, Warragul or Morwell.

As previously mentioned some time will elapse when using this system before a leak location can be made after a sheath failure has occurred; for this reason a contactor system using another pair as an alarm pair is also being installed so that a direct comparison of the efficiency of the two systems can be made.

Where the cable is laid in conduit, no difficulty is experienced in installing test points and contactors at any time, as manholes are available. On the buried section however, where the cable is laid at a depth of four feet and all joints are also buried, connection of any gas alarm equipment should be made during cable installation to obviate the necessity for excavating at a later date. The contactors are installed at intervals of 2,000 yards and are generally located at the same joint as the buried loading coil pot. The contactors are the standard contactor and terminal box (Serial 421/65) and are mounted above ground in a small reinforced concrete cabinet fitted with a lockable steel door. Connection to the cable is via lead tubing (Serial 421/35) but the lead is insulated from earth with a plastic wrapping.

Pressure reading test points are available at each contactor, and additional ones have been installed midway between the contactor locations. Similar plastic covered lead tubing is used to connect them to the cable, the tubing being terminated in a dummy sleeve about 6 in. long by 1 in. diam. A valve holder and schrader valve are inserted in this sleeve which is mounted in a No. 2 pit.

These insulated leads can also be used as test leads for subsequent electrolysis testing. An insulated copper conductor is soldered to the cable sheath at the opposite end of the joint to where the air lead is connected and both connections can be used for measuring any current flowing in the sheath. The normal air pressure in the cable is 10 p.s.i. above atmospheric pressure and the contactors are tentatively adjusted to operate at 5 p.s.i.

(ii) **Sydney-Melbourne** (600 miles). The system is the one already described as used in Germany. It is being supplied by Felten and

Guilleaume who are the contractors for the supply of the cable. The small U-tube manometers (contactors) used in this system are installed inside copper manometer casings mounted on top of the copper sleeve surrounding the cable joint. Provision is made in this casing to terminate the alarm pair on a pair of tags. Although not part of the Felten and Guilleaume system, a field order wire is being provided in the cable and is teed out to a second pair of tags. A special jack is used to make external connection to both pairs of wires. A fitting containing a schrader valve core is also attached to the manometer casing to enable pressure readings to be obtained.

The copper sleeve and the manometer casing are placed inside a cast iron jointing box (with a removable cover to provide access to the alarm pairs and the gas test point) the space between the fittings being filled with petroleum jelly.

Where the cable is laid in ducts, the joint box is mounted on the wall of a manhole, but for armoured cable, the box is buried direct in the ground about two feet deep. It is covered with a concrete slab with a hole in the centre, giving access to the removable cover in the joint box. Although the cable is laid at a depth of four feet, the reduced earth cover at the joints will result in less excavation being needed whenever access to the cable is required.

This method is being used for the first sections of cable laid from the Sydney end, but the use of different types of preformed manholes is being investigated. These manholes would be buried with about 18 in. of cover over the lid and it is possible that a change to the use of a buried manhole may be made for some portion of the route.

As the cable is laid in lengths of 500 yards there is another joint between each manometer joint. These are either loading coil, balance or building out joints, but in all cases the joint is protected with a cast iron jointing box. Neither the alarm pair nor the field order wire is brought out at this joint, but provision is made for reading the air pressures by fitting a B.P.O. type of a schrader valve mounting on the copper sleeve.

A special panel containing a single flow-meter, pressure gauge and a number of control taps is being provided in each repeater building to feed air to the coaxial cables on each side of the repeater. Cylinders of air are being placed in each repeater building and permanently connected to the cable

An alarm to operate when the contents of the cylinder reach a predetermined value will also be provided. The normal air pressure in the cable is 12 lb. per sq. in. above atmospheric pressure and the contactors are adjusted to operate at 8 lb. per sq. in. The system is therefore arranged as a "continuous flow system" and thus the full benefit of the contactors used with a "sealed system" is not obtained. Further tests and observations will be made when the system is placed in service and amendment to the design made if necessary.

(iii) **Adelaide - McLaren Vale** (25 miles). A special system has not been purchased for this cable. The gas control enquipment at each repeater and terminal station consists of an air cylinder, control taps and a flow-meter. The flowmeter covers the range 0.2 to 5 cub. ft. of air per hour and alarm contacts have been fitted locally. The operating point is continuously variable over most of the scale, but the tentative setting is at 1 cub. ft. per hour. Further adjustments will be made later when the "normal" leak has stabilised. An alarm to indicate low contents in the cylinder will be fitted later. The contactors are the standard combined bellows and terminal unit (Serial 421/65) and are fitted approximately 2 and 4 miles from the repeater stations. The nominal air pressure in the cable is 10 lb. per sq. in. above atmospheric pressure and the contactors are set to operate at 7 lb. per sq. in. Manholes consisting of a 4 ft. diameter concrete pipe, with surface mounting lids, have been provided at all joints on the armoured section of the cable, and the contactors are mounted on the wall of the manhole.

Test points are available at each station and at each contactor but initially are not being fitted at other intermediate points. As access to the cable is readily available at each joint, the fitting of test points at a later date will present no great difficulties. However, the first repeater section from Adelaide has been fitted with test points midway between the existing points to enable artificial cable faults to be placed on the cable and the operation of the alarm system observed.

(iv) **Brisbane-Tweed Heads** (70 miles). The gas control equipment in the repeater and terminal stations will consist of an air cylinder (with associated low contents alarm), control taps and a flow-meter. Contactors to Serial 41/65 will be located at intervals of approximately 2 and 4 miles from the repeater stations.

SUGGESTED REQUIREMENTS FOR AUSTRALIAN SYSTEMS

As no practical experience was available in Australia regarding the application of gas pressure to coaxial cables, the advantages and disadvantages of overseas installations were examined and arrangements made for trial installations of the German and Swedish systems described.

From an examination of data relating to these systems and to other overseas practices and also as a result of preliminary experience with the Swedish system, a better appreciation of the requirements of a gas pressure alarm system on coaxial cables has been obtained. It is felt that the system should be generally along the following lines but modifications may be necessary as the result of field experience:—

(i) The most important function of the system is to protect the cable and reduce the circuit interruptions to a minimum and to achieve this object, sufficient air must be available at a sheath failure to prevent water from entering the cable. The quantity of air that can be passed along a cable depends on the pneumatic resistance of the cable and the pressure gradient in the cable. The quantity of air that escapes is dependent on the size, type and position of the sheath failure, and the ability to maintain sufficient air supply inside the cable at the fault. For these reasons it is considered that an air supply should be permanently connected to the cable at each repeater station and be available to automatically replace any air that escapes from the cable. Air cylinders 5 ft high, 9 ins. diameter and containing 200 cub. ft. of air at atmospheric pressure have been standardized for this purpose.

(ii) The need to use contactors along the cable has been closely examined. The operation of a contactor gives warning that the air pressure in the cable at some point has been reduced to a predetermined figure and the identification of the contactor (by either manual or automatic measuring of the loop resistance) indicates the locality of the low air pressure. The next step is to connect cylinders of air to the cable in the vicinity of the fault. Subsequent action will depend on the nature of the fault.

Although the application of a "continuous flow" system will affect the pressure gradient in a cable which normally results after a fault occurs in a sealed system, and will therefore possibly interfere with the operation of the contactors, the installation of contactors is a wise precaution as it will give early advice of a faulty condition involving the larger size holes.

A two mile spacing is thought to be satisfactory and as a repeater station is approximately 6 miles in length, contactors should be installed about the 2 and 4 mile points. The actual positions will depend on the location of joints in the cable.

(iii) Test points are required for measuring the air pressure in the cable and are also used for injecting radon or freon into the cable during fault location. There is considerable difference of opinion regarding the method of housing test points and the most suitable means has yet to be determined but spacing of test points at intervals of approximately 1,000 yards should normally be provided.

(iv) The gas control equipment to be placed in a repeater building will depend on a number of factors and different types of equipment and methods of mounting are being examined but the following are the main items that appear to be necessary:—

(a) Regulator—Double reduction, air regulator (Serial 414/5) has been standardized for use with the air cylinder.

(b) An alarm that will operate when the contents of the cylinder are reduced to a low level. It is suggested that the alarm could be given when the air pressure in the cylinder is 300 lb. per sq. in. and work on a 2,000 lb. per sq. in. contactor gauge to operate at this pressure is in hand.

(c) Separate air connections are required to each coaxial and minor trunk cable terminating in the building, and each connection should contain a stop tap, flow-meter and non-return valve.

The non-return valve is required to prevent interchange of air between the cables. The flow-meter (probably of the type in which the air pressure maintains a small ball floating in a vertical transparent tube) is required to indicate the normal flow of air into the cable caused by minute leaks throughout the cable. The presence of a new leak would result in an increased flow of air and would be detected on the regular reading of the flow-meter if not reported earlier by the operation of a contactor. Electrical contacts could be fitted to these meters to give an alarm when the flow reached any desired figure, but this may not be necessary.

USE OF RADON AND FREON

From Appendix 1, it appears certain that radon and freon will need to be used for the final location for the majority of sheath failures. Present overseas policy for coaxial cable is to locate the leak as accurately as possible using the G.P.A. system itself, say within 200-500 yards, and then make the final location with radon or freon. In this case usually one, or for a speedier location, two charges of radon would be sufficient.

The radon location technique has now been developed to the stage where it can play an increasing part in finding sheath failures. Staff in Sydney have been trained in its use, and before long other trained personnel will be available to locate faults along the route of the cable.

There appears to be no reason then why radon should not play the major role in the location of the leak rather than the minor one. Using radon injections, at four different locations for instance, it would only be necessary to know the initial location of the leak to an accuracy of about one mile. This would enable the use of a simple and inexpensive G.P.A. system using flow-meters or flow-raters in each repeater station. However, the effectiveness of radon location on cables buried at a depth of 4 feet has still to be determined.

G.P.A. SYSTEM TO BE USED ON PARALLEL TRUNK CABLES

The system to be used on these cables will be governed by the type used on the coaxial cables. If contactors are fitted to the coaxial cable at 1,000 or 2,000 yard spacing, then the trunk cable should be treated the same. If contactors are only fitted at two mile intervals on the coaxial cable, then it may be necessary to fit contactors at shorter intervals to give sufficiently early warning of a severe leak.

If the method of measurement of gas flow is to be used, then there is no reason why it could not be applied to the trunk cable other than for the reason above, i.e., that there is no difficulty with insufficient warning being given of the occurrence of a severe leak.

CONCLUSION

Due to the importance of the coaxial cables and the costs of fault location and restoration of service, every attempt within economic limits will be made to ensure that a satisfactory jointing technique is employed and that the cable is adequately protected from mechanical damage, disturbance in manholes, electrolysis, chemical corrosion and termite attack in the most efficient manner during installation. This being so, a low fault incidence in service due to sheath failure can reasonably be anticipated.

Gas pressure alarm systems are being installed on each cable and as different types are available, comparison of the operation and efficiency of each will be obtained. The development of a system most suitable for use under Australian conditions will result from this examination.

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APPENDIX I COAXIAL CABLES—PRECIS OF LEAK LOCATION METHODS

Description of system. Col. 1.	Location of large sheath fracture. Col. 2.	Location of small sheath fractures. Col. 3.	Location of hair cracks, small pinholes, etc. Col. 4.
Sealed System—Australia (quad cables) Contactors at 1,000 or 2,000 yards spacing.	1. First contactor to operate gives accuracy to 1,000 or 2,000 yards. 2. Visual examinations of cable route will then usually disclose damage from the ground surface. 3. If not proceed as in column 3.	1. Unless very accurate and stable contactors are used, operation of contactors could be misleading due to small pressure gradients—accuracy may be then 2,000 yards. 2. Pressure gradient curves will need to be taken and corrected for height, temperature, etc., and will then give accuracy to say 200 yards.	1. Contactors cannot be used for accurate location due to minute pressure gradients. 2. Pressure gradient curves cannot be used successfully on all occasions. Use of small flow-meters at joints gives the direction of flow and narrows down area for final examination. 3. If accurate location is required, radon or freon would be used.
Sealed System—England. Contactor in each repeater station plus test valves at 1,000 yard intervals.	1. Contactors indicate the faulty repeater section only. 2. Measurement of pressure gradients will indicate location of the leak accurately. 3. Use freon or radon for final location if visual examination does not disclose leak.	1. Contactors indicate the faulty repeater section only. 2. Measurement of pressure gradients will give a reasonably accurate position of the leak (say 500 yards). 3. Use freon or radon for final location.	1. Contactors will indicate the faulty repeater section. 2. Measurement of pressure gradients will not add greatly to this accuracy. 3. Final location by radon or freon.
Continuous Flow System—Sweden Gas flow measurement method; signal manometer with air reserve in each repeater station.	1. An accuracy of $\pm$ 2% of the repeater length is claimed, and this is possible without having access to the cable at any point between repeater stations for pressure reading. 2. Final location by visual inspection. 3. If not proceed as in column 3.	1. An accuracy of $\pm$ 2% of the repeater length is claimed, and this is possible without having access to the cable at any point between repeater stations for pressure readings. 2. Final location by radon or freon.	1. An accuracy of $\pm$ 2% of the repeater length is claimed, and this is possible without having access to the cable at any point between repeater stations for pressure readings. 2. Final location by radon or freon.
Sealed System—Germany. Contactors at 1,000 yard intervals.	1. Contactor operation will give location within 1,000 yards. 2. Visual examination of cable route will then usually disclose damage. 3. If not proceed as in column 3.	1. Accurate contactors will give location within 1,000 yards. 2. Final location using freon or radon.	1. Contactors indicate approximate area of fault. 2. Pressure gradient curves will not add greatly to this accuracy. 3. Final location by radon or freon.

METHODS OF NUMERICAL FILTER DESIGN—PART VII

*E. RUMPELT, Dr.Ing.**

12. THE OPERATION OF FILTERS IN PARALLEL

Frequently, a combination of signals coming from some branch in a circuit and occupying some frequency band must be separated by filters into several smaller bands and these bands directed to separate loads. Alternatively, such filters are required to assemble at one branch in a circuit a set of signals coming from different origins and occupying separate frequency bands. Cases like these arise, for example, at the sending and receiving ends of carrier telephone systems in which several telephone conversations are transmitted simultaneously over one medium. It is then necessary to parallel the separating or combining filters at one end and, when doing this, it must be made certain that the filters do not disturb one another in their operation.

The simplest case is a low-pass filter and a high-pass filter circuited in parallel at their input terminals and connected to a common source with constant and resistive internal impedance. At their output terminals the filters are terminated separately by constant and resistive loads. It is obvious that filters designed in the ordinary way for operation between resistive terminations cannot without some alteration be used under such changed terminating conditions. Here each filter is not only terminated at its input end by the resistive source impedance, but also by the input impedance of the other filter. This must inevitably disturb to some extent the pass-band performance of the filters if not properly taken into account during the design. In the pass-band of each filter the other filter has its stop-band and the mutual disturbances would become particularly serious if the filters had impedance zeros in their stop-bands. This always happens when filters designed in the normal way have m-derived or double-derived image impedances.

One way of overcoming this mutual interference is to connect the two filters to the source separated by a hybrid transformer. If the hybrid is balanced with respect to the two filters, their inputs are fully decoupled and cannot interfere with each other. This method must always be applied if the pass-bands of the filters are overlapping. It is done at the cost of additional loss in the hybrid circuit, which is 3 db in each path if the hybrid is symmetrical.

There are other methods which avoid a hybrid transformer and the additional loss attached to it. In these methods the paralleled ends of the filters are so modified that the stop-band admittance of one filter largely compensates the reactive component of the pass-band admittance of the other filter. Thus, both filters mutually improve rather than disturb each others pass-band performance.

* See page 298, Vol. 12, No. 4.

12.1 Principal Impedance Considerations of Filters Connected in Parallel. The methods of connecting filters in parallel at one end are based on a fundamental law of network theory concerning the admittance at any terminal pair of a linear, passive network. If such an admittance has a resistive component which is constant from zero to infinite frequency, then its reactive component must be either zero or the admittance of a reactance circuit which can be separated from the network. The same law also holds if the word "admittance" is replaced by the word "impedance". Such an admittance or impedance may be a combination of admittances or impedances of several networks.

Resistively terminated filters have substantial resistive admittance components only in their pass-bands. In their stop-bands the admittances are practically reactive because the filters are reactance fourpoles and there is virtually no interaction between filter input and output owing to the large image attenuation.

If a filter has m-derived or double-derived image impedances and is terminated at its output by a constant resistance which is well matched to the image impedance in the practical pass-band, then its input admittance within this band is very nearly resistive and varies only slightly from a constant value. If two or more filters of this sort with confluent pass-bands from zero to infinite frequency are connected in parallel and the resistive parts of their input admittances combine to an approximately constant value at all frequencies, then it must be possible according to the above-mentioned law to extract from the inputs of these filters reactances to such an extent that the reactive admittance component of the filter combination nearly disappears at all frequencies. This is an ideal operating condition because the input impedance of the filter combination can be matched to a constant terminating resistance.

If there are gaps in the frequency characteristic of the combined resistive admittance component, or if this characteristic does not extend from zero to infinite frequency, then a residual reactive component will remain which, however, may be reduced by means of an additional susceptance annulling network across the input of the filter combination so as to cause no disturbing reflection losses in the pass-bands of the individual filters.

12.2 Modification of m-Derived and Double-Derived Filters for Operation in Parallel with Other Filters. On the basis of the above principle, filters which are to operate in parallel at one end are, as a rule, designed to have m-derived image impedances at both ends. At the common end the image impedance must be mid-shunt types, i.e., the matching sections there start with shunt branches. The latter are the reactances which must be omitted from the common end of each filter. The resistive components of the input admittances of the filters are not affected by this circuit modification, but the disturbing effects of the input shunt branches on the passband performance of the paralleled filters, in particular short-circuits due to reactance zeros, are removed.

The design of the matching sections of such filters is carried out on the same principles as shown earlier in paragraph 5 for ordinary filters. Frequently it is not the insertion loss in the pass-bands of the individual filters, but the return loss at the common end of the filter combination in the various pass-bands which determines the choice of the parameters of the m-derived image impedances. It is then advisable to make allowance for a possible reduction by a few db of the theoretical return loss minimum by the residual susceptance at the common end.

Sometimes, stringent return loss requirements in the practical pass-bands together with narrow transition bands make it necessary that the filters have double-derived image impedances at their terminals. At the common end, where a shunt reactance must be extracted from each filter, the double-derived image impedances must be mid-series types. The corresponding matching sections normally start with a series branch, but they can be so transformed that they start with a shunt branch which is then omitted. This will be shown in the case of a low-pass filter matching section.

A matching section for translating a mid-series constant-k image impedance into a mid-series double-derived image impedance is produced by first series-deriving a constant-k half-section with a factor m and then applying to this m-derived half-section a shunt-derivation with another factor, m'. The two half-sections, the m-derived one and the double-derived one, are joined at the terminals with identical m-derived image impedances and the combination has then a constant-k image impedance at one end and a double-derived image impedance at the other end. For the case of a low-pass filter the configuration of the complete matching section is shown in Fig. 16 and its component values are as follows:

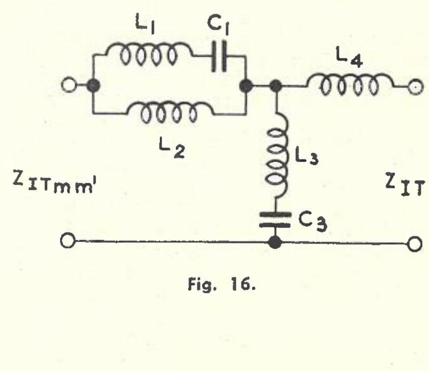

Fig. 16.

$$L_1 = \frac{m'(1-m^2)}{m(1-m'^2)} L_o$$

$$L_2 = m\,m'L_o;\quad L_4 = m\ L_o$$

$$L_3 = \frac{1-m^2}{m(1+m')} L_o$$

$$C_1 = \frac{m(1-m'^2)}{m'} C_o$$

$$C_3 = m(1+m')\,C_o$$

L_o and C_o are the components of the constant-k half-section from which the matching section is derived.

The matching section can now be transformed into the equivalent network shown in Fig. 17, with the following component values:

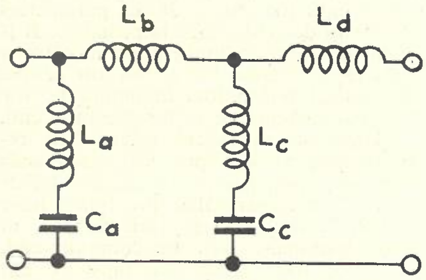

Fig. 17.

$$L_a = \frac{1-m^2}{m(1-m'^2)} L_o$$

$$L_b = m\,L_o\,;\quad L_d = m\,m'L_o$$

$$L_c = \frac{1-(m\,m')^2}{m\,m'(1+m')} L_o$$

$$C_a = m(1-m'^2)\,C_o$$

$$C_c = m\,m'(1+m')\,C_o$$

In this network the resonant circuit L_aC_a produces the attenuation peak at $\Omega_{\infty 2}$ and the resonant circuit L_cC_c produces the attenuation peak at $\Omega_{\infty 1}$, where both peak frequencies are given by the relations of Eq. (5.14). The resonant circuit L_aC_a is omitted when the matching section is at the common end of a low-pass filter which is to be circuited in parallel with other filters.

12.3. Reduction of the Residual Susceptance. The reactive admittance components at the common ends of the modified, parallel-circuited filters cancel one another to a large extent. Any residual susceptance in the pass-bands of the filters can be reduced by the susceptance annulling network mentioned earlier, which is circuited across the common end. This is a reactance network whose required reactance characteristic as a function of frequency can be determined either by measuring the impedance at the common end of the filter combination at a suitable series of frequencies or by a corresponding impedance calculation. As the latter is usually rather cumbersome, it is preferable to determine the impedance by measurement.

A susceptance annulling network consists of several series resonant circuits in parallel connection, usually one for each gap between successive pass-bands, and resonating approximately in the centre of the gap. If the lowest pass-band does not start at zero frequency, one series resonant circuit must resonate at a frequency below this pass-band, and if the highest pass-band does not extend to infinite frequency, one series resonant circuit must resonate at a frequency above this pass-band.

In the simplest case, the parallel combination of a low-pass filter and a high-pass filter, the susceptance annulling network is therefore a single series resonant circuit resonating at a frequency between the cut-off frequencies of the two filters. A perfect compensation of the residual susceptance is possible only at two frequencies, one in the pass-band of the low-pass filter and the other one in the pass-band of the high-pass filter. By properly selecting these frequencies (somewhere near the practical pass-band limits) the susceptance compensation is usually quite satisfactory in the whole of the practical pass-bands. If a better compensation is required, it can be obtained with two seriess resonant circuits, instead of one, which are connected in parallel and resonate at two different frequencies between the practical pass-band limits. Perfect susceptance compensation is then possible at two frequencies in each pass-band and the overall compensation is improved accordingly.

12.4 Avoidance of Susceptance Annulling Network. Sometimes, the use of a special network for susceptance compensation is not justified if the specifications concerning the pass-band performance of a filter group are only moderate. The factor m of the m-derived reduced matching sections at the common ends of the filters is then not chosen for flattest resistive components of the input admittances but for best compensation of their reactive components in the practical pass-bands. This will be shown in the example of a low-pass and high-pass filter combination.

It will be assumed that, at their independent output ends, the filters have m-derived image impedances which, in the the practical pass-bands, are well matched to the terminating resistances. In the practical stop-bands the filters should have an image attenuation which is large enough to prevent marked interaction between input and output of the filters. Disregarding the transition range, the input impedance of each filter at the common end may therefore with reasonable accuracy be considered as the sum of the series arm reactance of the reduced matching section and the mid-series type of constant-k image impedance. This arrangement is shown in Fig. 18.

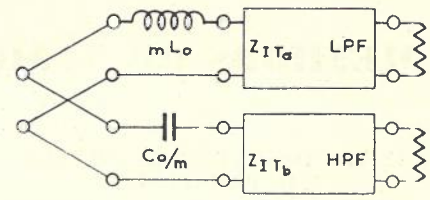

Fig. 18.

The input impedances are:
(a) Low-pass filter

$$Z_a = j\omega m\,L_o + R_o\sqrt{1-\omega^2/\omega^2_{ca}} \qquad (12.1)$$

with $L_o = R_o/\omega_{ca}$; ω_{ca} = cut-off angular velocity.

(b) High-pass filter

$$Z_b = \frac{m}{j\omega C_o} + R_o\sqrt{1-\omega^2/\omega^2_{cb}} \qquad (12.2)$$

with $C_o = 1/R_o\omega_{cb}$; ω_{cb} = cut-off angular velocity.

By referring the impedances to the nominal image impedance, R_o, of the filters and the frequencies to the cut-off frequency of the low-pass filter:

$$z_a = \frac{Z_a}{R_o}\quad z_b = \frac{Z_b}{R_o}\quad \Omega = \frac{\omega}{\omega_{ca}}$$

$$k = \frac{\omega_{cb}}{\omega_{ca}} > 1$$

the impedance functions become:

$$z_a = j\Omega m + \sqrt{1-\Omega^2} \qquad (12.3)$$

$$z_b = \frac{mk}{j\Omega} + \sqrt{1-k^2/\Omega^2} \qquad (12.4)$$

Considering now the frequency range of the practical pass-band of the low-pass filter, i.e. $\Omega<1$, the high-pass filter impedance is negative imaginary (capacitive) and may be written as follows:

$$z_b = \frac{1}{j\Omega}\left(mk + \sqrt{k^2-\Omega^2}\right) \qquad (12.5)$$

For calculating the input admittance of the two filters connected in parallel, the impedance function of the low-pass filter is expressed in reciprocal form, giving:

$$\frac{1}{z_a} = \frac{\sqrt{1-\Omega^2} - jm\Omega}{1-(1-m^2)\Omega^2} \qquad (12.6)$$

The resistive part of this expression corresponds to an m-derived mid-shunt image impedance. The reactive part should be cancelled as well as possible by the admittance of the high-pass filter, i.e.:

$$\frac{j\Omega}{mk+\sqrt{k^2-\Omega^2}} - \frac{jm\Omega}{1-(1-m^2)\Omega^2} = 0 \qquad (12.7)$$

There are two parameters, m and k, in this equation but only the parameter m can be chosen freely so as to yield a reasonable cancellation of the reactive admittance components. The parameter k is the ratio of the cut-off frequencies of high-pass and low-pass filter, and is determined by the filter specifications.

In the pass-band of each filter a perfect susceptance compensation can therefore be obtained only at one frequency which is best put somewhat inside the practical pass-band limit. The selected frequency for the low-pass filter is, in normalised form, substituted for Ω in Eq. (12.7). Rearranging this equation gives the following expression for calculating m:

$$m^2 + m \frac{\sqrt{k^2 - \Omega^2}}{k - \Omega^2} = \frac{1 - \Omega^2}{k - \Omega^2} \quad (12.8)$$

It is advisable to make a check of the residual susceptance at a series of frequencies in the practical pass-bands to make sure that the frequency of perfect susceptance compensation has been selected properly. As an example, it will be assumed that the practical pass-band limit of the low-pass filter is $\Omega_l = 0.90$ and that the ratio of the cut-off frequencies of high-pass to low-pass filter is $k = 1.10$. Choosing $\Omega = 0.80$ as the frequency of perfect susceptance compensation yields, via Eq. (12.8), $m = 0.386$. The residual susceptance, $1/x_r$, at the common end of the combined filters is then in the pass-band of the low-pass filter:

Ω	0	0.3	0.5	0.6	0.7	0.8	0.85	0.9
$1/x_r$	0	0.077	0.111	0.112	0.086	0	0.095	0.267

This result is quite satisfactory. At the limit of the practical pass-band the insertion loss due to input mismatch is only 0.08 db.

The susceptance compensation is the same in the equivalent part of the pass-band of the high-pass filter. This means that the pass-band specifications for the two filters must be essentially the same. If they are different, particularly if a wider coverage of the theoretical pass-band by the practical pass-band is required for one filter as compared with the other one, the best overall susceptance compensation will be obtained with two different m-values for the reduced input matching sections of the two filters. The calculations become more complicated but the principal considerations remain unchanged.

12.5 The Stop-Band Performance of Filters Operating in Parallel. Some consideration must be given to the insertion loss in the stop-bands of filters which are connected in parallel at one end. As the terminating condition at the common end for the individual filters is different from the normal case of filters operating on their own between resistive terminations, the reflection loss has changed at the common end. Excepting the transition bands, it may be assumed with sufficient accuracy that the reactive component of the impedance at the common end of the filter combination has been cancelled and that its resistive component is constant. Therefore, if a matched voltage source is connected to the common end, the voltage across it is one half of the e.m.f. of the source. With this in mind, the insertion loss in the stop-band of any one of the paralleled filters, at frequencies where another one of these filters has a pass-band, can be derived in the following way:

According to definition the image attenuation of a filter is:

$$\alpha = \frac{1}{2} \ln \left|\frac{V_1 I_1}{V_2 I_2}\right| \text{ (nepers)}$$

$$= 10 \log \left|\frac{V_1 I_1}{V_2 I_2}\right| \text{ (db)}$$

where V_1 and V_2 are input and output voltages and I_1 and I_2 input and output currents, respectively, of the filter when terminated by its image impedance.

With input and output image impedances designated by Z_{I1} and Z_{I2}, respectively, we have:

$$I_1 = V_1/Z_{I1}; \quad I_2 = V_2/Z_{I2};$$

and therefore

$$\alpha = 20 \log \left|\frac{V_1}{V_2}\right| + 10 \log \left|\frac{Z_{I2}}{Z_{I1}}\right| \quad \ldots\ldots (12.9)$$

In the stop-band of a filter any interaction between input and output is so small that it can be neglected. On this basis the output voltage for resistive termination of the filter can be calculated with the help of Thevenin's theorem to be:

$$V'_2 = 2 V_2 \frac{R_2}{R_2 + Z_{I2}} \quad \ldots\ldots (12.10)$$

where R_2 is the terminating resistance at the filter output.

For the same reason the voltage at the common end (input) of the filter is not influenced by the output terminating condition and, as mentioned earlier, is practically one half of the e.m.f. E of the source:

$$V_1 = \frac{1}{2} E \quad \ldots\ldots (12.11)$$

Assuming equal source and load resistances

$$R_1 = R_2 = R$$

the insertion loss of the filter is

$$A_L = 20 \log \left|\frac{E}{2V'_2}\right| \quad \ldots\ldots (12.12)$$

Introducing into this expression the relations of Eqs. (12.9), (12.10) and (12.11) yields:

$$A_L = \alpha + 20 \log \left|\frac{R + Z_{I2}}{2R} \sqrt{\frac{Z_{I1}}{Z_{I2}}}\right| \quad \ldots\ldots (12.13)$$

Using the matching factors

$$p_1 = \left|\frac{Z_{I1}}{R}\right| \text{ and } p_2 = \left|\frac{Z_{I2}}{R}\right|$$

and considering that the image impedances in a stop-band are imaginary, Eq. (12.13) for the insertion loss can be expressed in the following way:

$$A_L = \alpha - 3 + 10 \log p_1 + 10 \log \frac{1 + p_2^2}{2p_2} \quad \ldots\ldots (12.14)$$

In these relations α is the image attenuation of the complete filter including the input matching section before its modification and Z_{I1} is the input image impedance of this section.

Comparing Eq. (12.14) with Eq. (4.15), the latter being the insertion loss in the stop-band of a filter on its own between resistive terminations, shows that the total reflection loss at the common end has changed

$$\text{from } \left(10 \log \frac{1 + p_1^2}{2p_1} - 3\right) \text{ to } 10 \log p_1$$

The modification of the input matching section has no influence on the above relations as long as the input voltage of the filter remains constant at E/2.

On the other hand, from a physical point of view it is obvious that an insertion loss peak would have been produced by every series resonant circuit which was shunted originally across the input of the matching section. When such a series resonant circuit is removed the corresponding insertion loss peak must also disappear.

This is not in disagreement with the relation of Eq. (12.14) because the reflection loss at the filter input, 10 log p_1, has a negative peak at an attenuation peak frequency of the matching section, as here $Z_{I1} = 0$. In Eq. (12.14) a negative reflection loss peak at the common end just cancels the corresponding positive attenuation peak of the matching section.

The image attenuation of the unmodified matching section and the input reflection loss may be combined mathematically. This is shown for a normalised low-pass filter as follows:

The image attenuation of the matching section, that is of an m-derived half-section is according to Eq. (5.27):

$$\alpha_{hs} = \coth^{-1} \frac{1}{m} \sqrt{1 - 1/\Omega^2} \text{ (nepers)}$$

This expression can be transformed into

$$e^{2\alpha_{hs}} = \left|\frac{\sqrt{\Omega^2 - 1} + m\Omega}{\sqrt{\Omega^2 - 1} - m\Omega}\right| \quad \ldots\ldots (12.15)$$

and $\alpha_{hs} = 10 \log \left| \dfrac{\sqrt{\Omega^2 - 1} + m\Omega}{\sqrt{\Omega^2 - 1} - m\Omega} \right|$ (db)

.... (12.16)

The input reflection loss is

$$10 \log p_1 = 10 \log \left| \frac{Z_{I1}}{R} \right|$$

with $Z_{I1} = Z_{1\pi m}$

$$= R_0 \frac{1 - \Omega^2 (1 - m^2)}{\sqrt{1 - \Omega^2}} \quad \text{.... .... (12.17)}$$

This is the m-derived mid-shunt image impedance of the normalised low-pass filter with the nominal image impedance R_0. The latter is very nearly equal to the terminating resistance R and the input reflection loss is therefore:

$$10 \log p_1 = 10 \log \left| \frac{(\Omega^2 - 1) - m^2\Omega^2}{\sqrt{1 - \Omega^2}} \right|$$

.... (12.18)

When the expressions of Eq. (12.16) and (12.18) are added the factor $(\sqrt{\Omega^2 - 1} - m\Omega)$ cancels and the combined loss is:

$$A_c = \alpha_{hs} + 10 \log p_1$$

$$= 10 \log \frac{(\sqrt{\Omega^2 - 1} + m\Omega)^2}{\sqrt{\Omega^2 - 1}}$$

.... (12.19)

The evaluation of this relation as a function of Ω for practical values of m (between 0.3 and 0.7) gives loss values which rise steadily from a minimum of a few db (depending on m) around $\Omega = 1.1$, to infinity at infinite frequency. The attenuation peak of the matching section at $\Omega_\infty = 1/\sqrt{1 - m^2}$ is contained in the cancelled factor and has therefore disappeared.

12.6. Insertion Loss in Transition Bands. In the transition bands between the pass-bands of filters operating in parallel, the resistive component of the common input admittance drops to practically zero if there is a marked gap between successive pass-bands. Not considering for the moment any susceptance annulling network at the common end, the reactive component of the input admittance passes through zero at one frequency at or near the centre of each transition band. This means that at such frequencies the input impedance of the filter combination rises to large values and the input voltage increases to a maximum approaching the e.m.f. of the source to which the common end of the filters is connected, as compared with half this voltage inside pass-bands. The insertion loss is therefore reduced by up to 6 db below the value calculated on the basis of the considerations in the previous paragraph.

This must be borne in mind when such filter combinations are used in two-way repeaters amplifying one frequency band in one direction and the complementary frequency band in the opposite direction (Fig. 19). In such an arrangement it is necessary to maintain sufficient loop loss in the repeater loop to avoid self-oscillations at all frequencies, including the transition bands.

Susceptance annulling networks produce in theory insertion loss peaks in the transition bands thus improving the insertion loss in these bands. In practice, however, the impedance of these networks is rather large and the peaks produced by them are therefore only small. For this reason it is advisable to consider the small additional loss only as a bonus to make up for deficiencies of the insertion loss due to inaccuracies in the realisation of the filters.

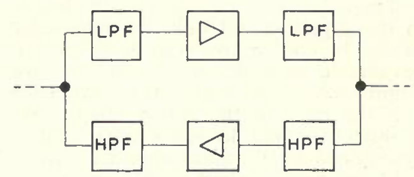

Fig. 19.

12.7. Operation of Filters in Series. If it is desired to operate filters in series, instead of in parallel, considerations analogous to those in the previous paragraphs can be applied. The matching sections at the common end to be modified are in this case mid-series m-derived or mid-shunt double-derived and properly transformed. The first series branches are omitted. Any excessive residual series reactance in the input impedance at the common end is adequately reduced by a reactance annulling network which consists of parallel resonant circuits resonating at frequencies in the transition bands and connected in series with the filter combination. The stop-band insertion loss is the same as for parallel circuited filters under equivalent conditions. As the practical field of application is very limited, this case will not be discussed further.

TELECOMMUNICATION SOCIETY OF AUSTRALIA — 2nd ANNUAL REPORT OF COUNCIL OF CONTROL FOR YEAR ENDING 30th APRIL, 1961

This year has been one of remarkable progress in the Society; thanks to the enthusiastic co-operation of State Committees (whose detailed work is recorded separately), Society activities have included well-attended lecture programs and visits in all States and the circulation of the Journal has doubled to over 6,000.

The number of pages per Journal has increased with each issue during the past year, reaching 92 pages with Volume 12, No. 6. Production costs have risen accordingly, and although offset by a satisfactory rising advertising income, still substantially exceed the revenue from subscriptions. The Society is grateful for the financial support it receives from the Postmaster-General's Department, and from its advertisers, which enables the Journal to be of increasingly greater service to its readers.

The increased size of the Journal has thrown a greater load on the Board of Editors; nevertheless, publication delays were largely overcome by the year's end. Mr. V. J. White, on leaving the Postmaster-General's Department, was replaced on the Board of Editors by Mr. D. P. Bradley.

The Council has been pleased to appoint Mr. V. J. White and Mr. J. Pollard as Life Subscribers in recognition of their outstanding services to the Society.

Council members for the year 1960/61 were as follows:—

Chairman: Mr. F. P. O'Grady, M.I.E. Aust., S.M.I.R.E.Aust. (Deputy Director-General).
Immediate Past Chairman: Mr. I. M. Gunn, M.B.E., A.M.I.E.Aust.
State Representatives:
N.S.W.: Mr. W. A. Wood.
Vic.: Mr. A. C. Wright, A.M.I.E. Aust.
Qld.: Mr. J. A. Pryor.
S.A.: Mr. D. B. Watson, B.Sc.
W.A.: Mr. E. L. Brooker, B.Sc., A.M.I.R.E.Aust.
Tas.: Mr. A. N. Birrell, B.E., A.M.I.E. Aust.
Editor-in-Chief: Mr. N. M. Macdonald, B.Sc., A.M.I.E.Aust.
Treasurer: Mr. W. J. E. Pollock, B.Com.
General Secretary: Mr. R. G. Kitchenn, B.Sc.(Eng.), A.M.I.E.E., A.M.Brit.I.R.E.

AUTOMATIC P.G. ALARMS FOR INDICATION OF CABLE FAULTS

*E. J. BULTE, B.Sc.**

INTRODUCTION

Underground cable faults, particularly in the larger exchange networks, cause considerable disruption to telephone service as well as involving the Department in heavy expenditure in material and manpower for their repair. In this regard, it is of interest to note that last year, in the Melbourne metropolitan area, approximately 30,000 services were put out of order in a single week as a result of water entering cables after prolonged rain followed a long dry period. The efforts necessary to locate and repair the damage in this case was obviously very considerable, and any preventive or mitigative measures which may be applied are well worth while.

One aspect which is very relevant to the question is the fact that, in the case mentioned, not one cable which was under gas pressure was affected. At the moment gas pressurisation is applied only to junction cables, because their freedom from faults is more important than subscribers' cables, and, also, gas pressure is much easier to apply in their case. Action is proceeding with a view to applying gas pressurisation to subscribers' cables, but it will probably take a long time to cover all cables successfully in this way.

Some work has also been done in an effort to detect incipient cable faults so that they may be cleared before they cause trouble, by the use of an automatic line routiner. (1) Studies in this direction, however, are still in the early stages in this country, and it may be some time before positive results can be expected. In any case, the use of automatic line-testing equipment would not assist in detecting all cable faults, unless the equipment were operated on a continuous basis, which is outside the scope of its design. Obviously, under such conditions, a cable sheath break could occur after an automatic line tester "run". It is therefore desirable to have an automatic indicator available which will operate immediately a group of subscribers become faulty, and the P.G. alarm is intended to cover this aspect.

THE INFLUENCE OF COMMON CONTROL EXCHANGE SYSTEMS

In 1954, the North Essendon Exchange was cut into service with Siemens No. 17 motor uniselector equipment (2). It was found that the particular circumstances which arise in the operation of this type of equipment (and which can occur with other modern types of equipment equipped with P.G. lockout facilities) are such that a serious subscribers' cable fault may occur and remain undetected for a long period during the hours in which the exchange is left unattended.

In this equipment, upon a subscriber lifting his receiver, a line finder is allotted which searches and extends his loop to a discriminating selector and control. The discriminating selector searches and finds a free junction to the main exchange. Dial tone is then transmitted to the caller. If the subscriber does not dial within a period of 40 seconds, the discriminating selector control forcibly releases the main junction and, finally, after the discriminating selector has run to the 52nd outlet, releases itself. The subscriber's loop holds the discriminating selector as a P.G., and the P.G. lamp on the linefinder glows. Such a release feature is necessary in a common control exchange such as this.

Under cable fault conditions, similar "pulsing out" actions take place, and, since no P.G.'s occur on the incoming first selectors in the main exchange, the staff in that exchange have no means of ascertaining the possibility of a subscribers' cable fault being present in the North Essendon exchange. As this Exchange is only staffed 7.00 a.m.-5.00 p.m., Monday to Friday, and 8.30 a.m.-noon, Saturday, serious cable faults can easily remain undetected for long periods thus leaving subscribers without service, and often making the work of clearing the cable fault more costly and time-consuming because water can penetrate further inside the cable. Also, more extensive charring of the cable insulating paper can necessitate extensive "piecing" operations.

DEVELOPMENT OF "SUNVIC" RELAY ALARM

Quite a few cable fault alarm circuits had been tried over the years, but no reliable equipment had been developed when North Essendon exchange was cut into service. At this exchange a special type of automatic operating D.C. power plant had been installed, involving the automatic switching in and out of one, two or three 100 amp. rectifiers, as required, combined with an automatic end cell switching arrangement. This scheme, which had been developed locally, based on some European practice which had come under notice, used "Sunvic" relays as its main marginal switching control device. As these relays appeared to operate satisfactorily in the power suite, the idea of using them for cable fault alarm purposes was conceived.

The Sunvic Hot Wire Vacuum Relay is a sealed tube a little larger than an ordinary radio valve. Its operation depends on the fact that, when an electric current is interrupted by the separation of two surfaces in a vacuum, no arc is formed. The actual separation need only be about .001 inches. A switch operation in a vacuum therefore requires only very light contacts and a very small current. The movement necessary to close or open the contacts is so small that it can

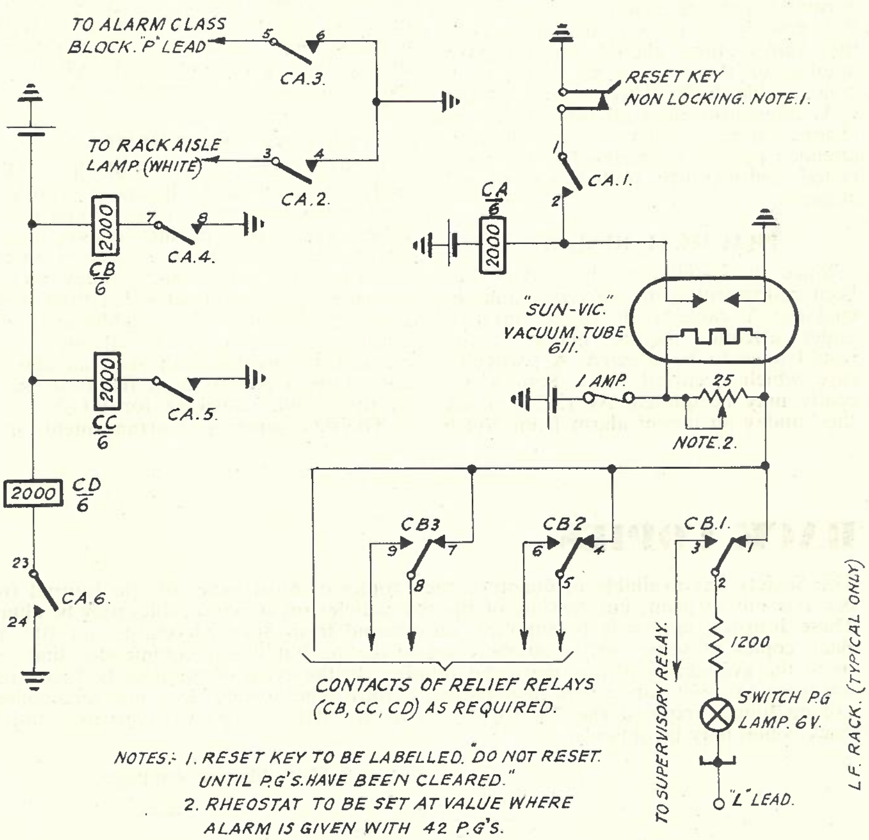

Fig. 1.—Cable Fault Alarm Circuit, "Sunvic" type.

* See page 80.

readily be provided by the thermal expansion of a wire through which the control current passes. The thermal wire consists of a number of turns of special steel wire wound between two steatite bobbins. When current is passed through the wire it expands and causes the control contacts to operate by a mechanical action connected to one of the bobbins. Tests made on a Sunvic relay showed that the margin of operate to non-operate current was less than 1%. It was also found that the operate current never varied.

The circuit shown in Fig. 1 was then developed and installed by the local staff. The operation is as follows:—

The P.G. lamps of the line finders obtain their battery feed via the shunted heater winding of the Sunvic tube. The shunt across the heater is adjusted so that the Sunvic relay will operate when a predetermined number of P.G. lamps are glowing. The number chosen initially at North Essendon was 30, but this figure has since been increased to 42. The figure chosen depends mainly on the character and incidence of traffic in the exchange and is such that the alarm will not operate during the unattended periods due to normal subscribers' telephone habits, as well as allowing for the usual number of isolated short-circuited lines expected to occur in the area.

Upon operation of the Sunvic relay, the C.A. relay operates and locks via the reset key. Relief relays CA, CC and CD operate. These relays in operating disconnect the tube from the P.G. lamp leads and place the lamps back to their normal battery feed source. This action is necessary to prevent overloading of the Sunvic tube should an excessive number of P.G.s occur by virtue of a major cable fault. The contacts of the C.A. relay also close circuits to the exchange alarm system, which in unattended periods is extended to the associated continuously staffed control exchange.

PRACTICAL RESULTS

Since its installation this device has been instrumental on many occasions in enabling a cable fault to be brought under attention before major repairs would have to be effected. A particular case which occurred on a Sunday recently may be quoted. At 1.45 p.m. on the Sunday an urgent alarm from North Essendon was received at the control exchange. An immediate investigation by the week-end fault staff indicated that a cable fault affecting 35 subscribers had occurred. Check by the Lines staff revealed that a 38 pair cable joint had developed a fracture in a one pair lateral and water had entered the joint. Repairs involved only drying out and some piecing within the joint. In this case, if the alarm had not been in operation, it would almost certainly have been necessary to replace two lengths of armoured cable, 24 ft. of which was laid under a concrete driveway. By contrast, at a nearby exchange, to clear a fault in a 1400 pair cable it was necessary to draw in a new length, a process which occupied approximately three days. Had a cable fault alarm been in operation, drying out operations could well have been completed in a matter of less than 8 hours.

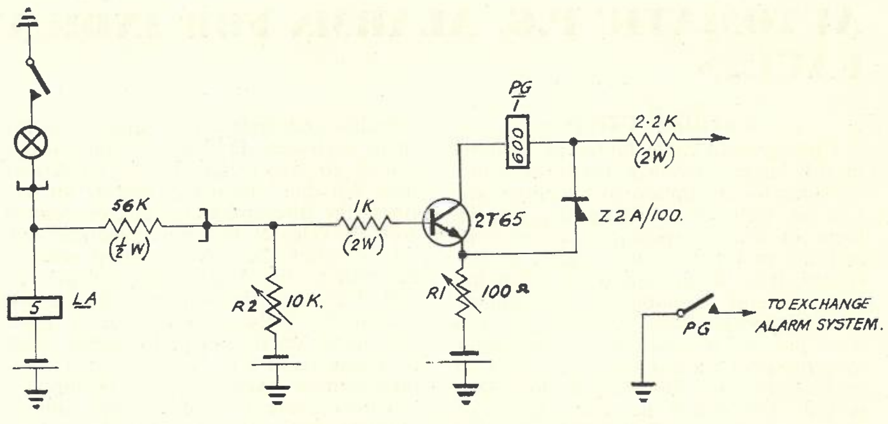

Fig. 2.—Cable Fault Alarm Circuit, Transistor type.

RECENT DEVELOPMENTS

In view of the success of the cable fault alarm at North Essendon, consideration has been given to extending it to other exchanges having conventional step-by-step equipment. Under present conditions of maintenance, many more exchanges are left unattended than was formerly the practice. In addition, it is considered that even in attended exchanges the existence of such an alarm can allow a reduction in the frequency of the regular checking for P.G.'s.

The P.G. supervisory arrangements are different in step-by-step exchanges, and consequently a different circuit was designed, using a transistor as the voltage sensing device as shown in Fig. 2. The operation of the circuit depends on the voltage developed across the LA relay in the standard alarm circuit by each P.G. alarm lamp. Each lamp draws a current of slightly more than 80 mA which gives a voltage drop across the 5 ohm LA relay of 0.4 volts. This is coupled to the base of a common emitter transistor circuit through a 56,000 ohm resistor and, if sufficient lamps are alight, causes the transistor to conduct and operate the P.G. relay. The number of P.G.s required to operate the relay can be set at any desired value by a combination of the two wire-wound potentiometers R_1 and R_2. This circuit has been installed in several exchanges to date, and it is planned to extend its installation to all exchanges in the Melbourne metropolitan area, at least. It has the advantages over the original North Essendon circuit in that it takes up less space, the components are cheaper, and it is much simpler to wire into the exchange equipment.

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BACK COPIES

The Society has available in quantity, back copies of most issues of the Journal from Volume 5 onwards. Volume 12, Number 1 is out of print, but reprints of the two articles on co-axial cables may be obtained for a total cost of 3/-.
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* For addresses see page 83.

CARRIER JUNCTION SIGNALLING RELAY SETS

L. A. WHITE*

INTRODUCTION

An integral part of the planning for the introduction of extended local service areas (E.L.S.A.) in Victoria on 1st May, 1960, required the provision of a large number of unit fee dialling junctions over cable carrier telephone systems between City West (Melbourne) exchange and the existing and proposed automatic exchanges in the Sub-metropolitan area. In this area new automatic exchanges at Dandenong, Croydon, Bayswater, Boronia and Lilydale, with a total equipped capacity of 10,400 lines were put into service on 1st May, 1960, coincident with the implementation of E.L.S.A. and automatic exchanges already existed at Frankston and Belgrave.

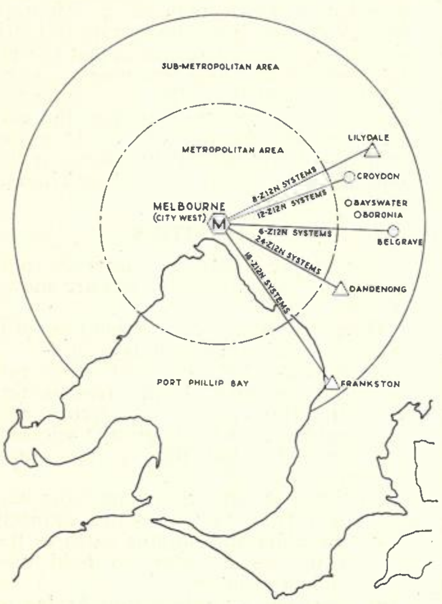

Fig. 1.—Interlinking carrier junction routes between Melbourne metropolitan and sub-metropolitan area automatic exchanges.

Fig. 1 shows the interlinking carrier junction routes between the metropolitan and sub-metropolitan areas. In general, the metropolitan area is within 15 miles of the G.P.O., and is one charging zone (Melbourne Telephone Zone) while the sub-metropolitan area is between 15 and 25 miles radius of the G.P.O. and contains several charging zones (Melbourne Outer Telephone Zones). Both these areas form the Melbourne Telephone District with unit fee calls between the adjoining zones.

To provide the required number of junctions to carry the unit fee traffic for the introduction of E.L.S.A. twenty-six 12-channel cable carrier systems were purchased from Siemens & Halske and installed to supplement the existing carrier routes and to establish a new carrier route to Lilydale exchange. A total of 760 carrier junctions equipped with new exchange signalling relay sets were put into service on 1st May, 1960.

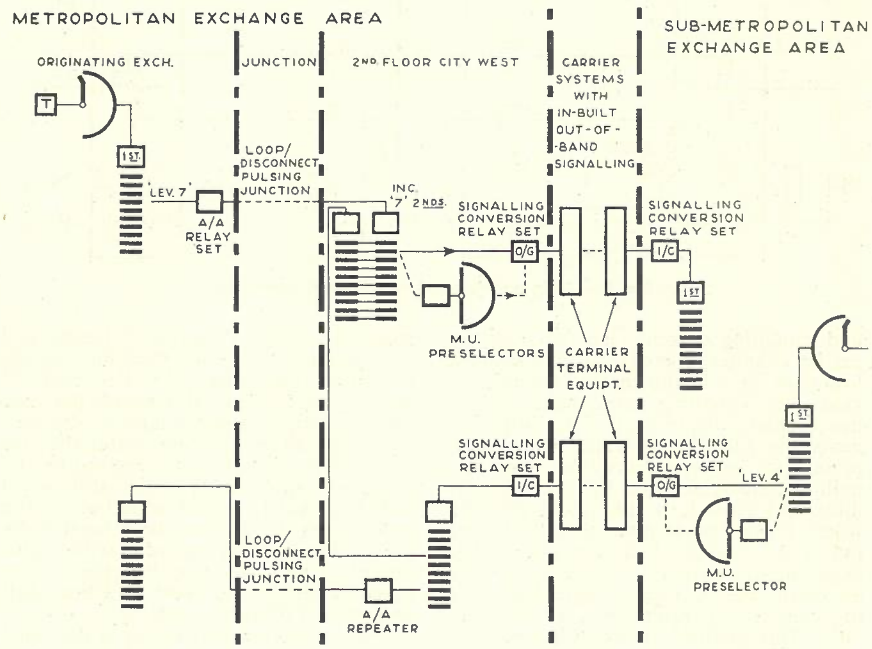

Fig. 2.—Typical trunking arrangements.

The purpose of this article is to describe the facilities and circuits of the relay sets developed for this application. In addition, trunking details, general principles of carrier system out-of-band signalling, and design requirements of exchange signalling relay sets for carrier junctions are described.

TRUNKING

Typical trunking arrangements are shown in Fig. 2. Access to metropolitan area from the sub-metropolitan exchanges is provided by a single digit access code, this being level 4 from 1st selectors at the sub-metropolitan exchanges.

Subscribers in the metropolitan area gain access to the sub-metropolitan exchanges from level seven of all metropolitan exchange first selectors trunked via second selectors located at City West exchange. Levels from the second selectors at City West connect to the carrier junctions provided to the sub-metropolitan exchanges.

GENERAL PRINCIPLES OF CARRIER SYSTEM OUT-OF-BAND SIGNALLING EQUIPMENT

Multi-channel carrier telephone systems of the latest type incorporate, as an integral feature of the design, signalling equipment using frequencies outside the speech band but within the channel bandwidth. This type of signalling over carrier systems is known as "BUILT-IN OUT-OF-BAND" or "OUT BAND". The signalling over carrier channels in which the signalling information is transmitted within the speech bandwidth as in the 2VF system which is common in our operator dialling trunk network is known in "IN BAND" signalling. Fig. 3 shows the relative positions of speech and signalling bandwidth within the channel bandwidth of "OUT BAND" signalling systems.

Out-of-band transmission systems make use of filter networks to separate the speech and signalling paths. A typical transmission arrangement is shown in Fig. 4. Modern carrier systems employ a channel bandwidth of 0-4 Kc/s. Filters are used to keep the speech bandwidth within the C.C.I.T.T. recommended limits of 300 c/s to 3.4 Kc/s and a signalling frequency of 3825 or 3850 c/s which is outside the speech bandwidth but within the channel bandwidth is employed.

Referring to Fig. 4, when an earth is applied to the send signalling lead from exchange "A" equipment the static relay is biassed in a forward direction resulting in the signalling tone being applied to the send transmission path. The low pass filter prevents the signalling tone being fed back into the exchange "A" equipment and also stops any of the upper speech frequencies that might cause signal imitation and result in production of false signals. Both speech

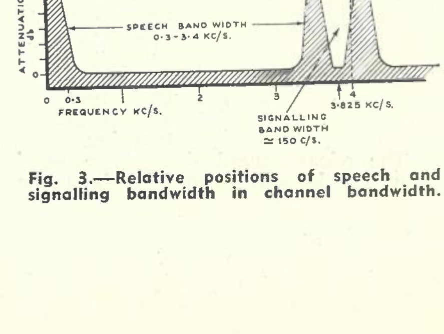

Fig. 3.—Relative positions of speech and signalling bandwidth in channel bandwidth.

* See page 80.

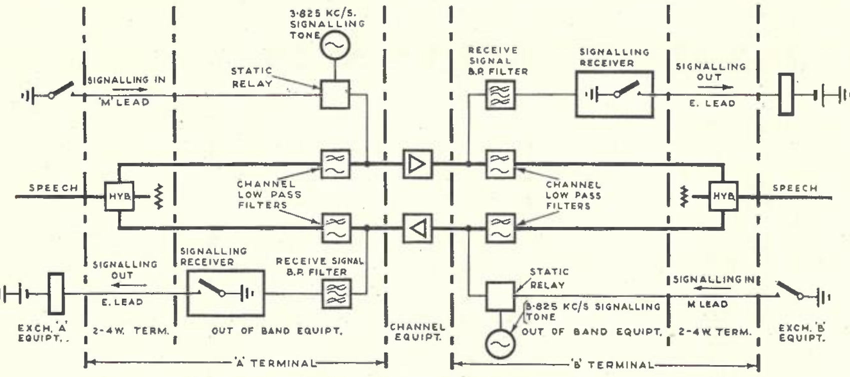

Fig. 4.—Basic principles of out of band signalling.

and signalling currents are fed over the carrier channel to exchange "B" where a low pass filter in the receive circuit prevents the signalling tone being fed to the exchange equipment and thus prevents the tone being heard when it is present during a conversation. The signalling tone is selected by a band pass filter and passed to the signal receiver where the signal frequency is converted into a D.C. signal which operates a relay in the detector circuit. This relay extends an earth on the receive signalling lead to operate the equipment at exchange "B". This method of signalling permits signals to be transmitted and received by both ends simultaneously.

The signalling leads with reference to the carrier system are generally designated "E" and "M" for the receive and send signal leads, respectively, although the German equipment supplied by Siemens and Halske use the designations "S2 out" and "S2 in". It is of interest to note the reason for the adoption of the designation, "E" and "M" lead signalling. The "E" is derived from Exchange equipment for this lead extends the signal from the carrier system to the exchange equipment. The "M" is derived from Modulator as the send lead is used to bias the modulator or static relay for blocking or transmission of signalling tone depending on the polarity of D.C. signals applied to the lead by the exchange equipment.

DESIGN REQUIREMENTS OF EXCHANGE SIGNALLING RELAY SETS FOR CARRIER JUNCTIONS

To provide the equivalent of a 2-wire auto-auto junction when using carrier junctions linking two local automatic exchanges it is necessary to provide an exchange relay set at both ends of the junction, that is, an outgoing relay set and an incoming relay set.

In the design of the relay sets, safeguards to eliminate no progress due to exchange equipment or carrier system faults have been provided, the following signals being regarded as essential:—

(a) from O/G end—Seizure
Impulse repetition
Clear forward.

(b) from I/C end—Answer
Clear back
Release guard
Blocking.

The release guard signal is returned from the incoming end to maintain an engaged condition on the outgoing end of a circuit until the incoming equipment has fully released and is ready to accept a further call, this avoids the need for a critically timed guard in the outgoing equipment and eliminates the risk of a follow-on call being received by the incoming equipment while still in a seized or partly seized condition if the time taken to release is exceptionally long. The release guard facility also provides for automatic busying at the outgoing end in the event of a line fault or system failure.

The blocking signal which is the same as the release guard signal is used to back busy from the incoming end to the outgoing end should the equipment at the incoming end be taken out of service for maintenance or routine purposes.

All the above signals can be obtained from a continuous signal code based on simple on/off conditions and is illustrated in Fig. 5. With this code the signal tone

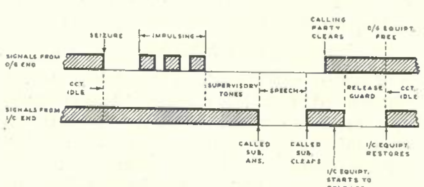

Fig. 5.—Basic Signalling Code.

is transmitted while the circuit is idle. On seizure at the outgoing end the tone is removed. Dial pulses are transmitted as pulses of tone corresponding to the break period of the impuse and on completion of dialling the tone is removed to hold the connection. When the called party answers, tone is removed from the incoming end. During conversation tone is disconnected in both directions. The clearback is indicated by the reconnection of tone at the incoming end and the clear forward by the reconnection of tone at the outgoing end. During the release sequence of the incoming exchange equipment the tone is disconnected to provide the release guard signal and is reconnected when the equipment has fully restored to normal.

"Tone-on-idle" signalling is preferred to "Tone-off-idle" for the following reasons:—

(i) While circuits are idle an interruption to the transmission path results in immediate busying of junctions.

(ii) During conversation when tone is removed short interruptions to the transmission path will not result in premature release of the connection.

A disadvantage of "TONE ON IDLE" is that the short interruptions of the transmission path result in pick-up of all idle incoming circuits and it is necessary to ensure that distribution and fusing arrangements are satisfactory to cover this event.

Further design requirements necessitated that access to the relay set be available from—

(i) the level of bimotional selectors direct.

(ii) the levels of bimotional selectors via motor uniselector preselectors.

(iii) an incoming 2-wire junction.

Because of the necessity to provide a test in facility for the motor uniselector preselector which requires a 550 ohm battery condition on the private to mark a free junction it is essential that the bimotional selector also obtaining access be of the S.E. 50 type. On levels outgoing from these selectors other than the carrier junction access levels earth testing is required and the S.E.50 selector is the only suitable switch under these circumstances.

FACILITIES

The circuits developed for the outgoing and incoming relay sets are shown in Figs. 6 and 7.

Outgoing Relay Set. Facilities provided by the outgoing relay set:—

(i) Provides 550 ohm battery on private to mark junction free for test in from motor uniselector preselector. S.E.50 group selectors can also test into a free outlet marked with battery.

(ii) When seized removes marking battery from "P" wire and connects guarding and holding earth to the C.B. and P. wires to hold preceding switches.

(iii) Provides a transmission bridge to feed speaking battery to the calling party.

(iv) Repeats impulses from the caller's dial to the carrier channel signalling path.

(v) When called party answers the reversal is repeated over the carrier channel signalling path to—
(a) operate the calling party's meter, and
(b) reverse the polarity of the calling line for supervisory purposes.

(vi) When the calling party clears, provides an unguard on the "P" wire to initiate the release of preceding switches, then reguards the "P" wire until the incoming relay set and selector at distant exchange fully restore to normal.

(vii) Ensures that the holding relays of preceding switches release before the reguard is applied.

(viii) Prevents seizure of the junction if a selector tests in during the release unguard period.

(xi) Provides for group busy to prevent hunting of preselectors during congestion.

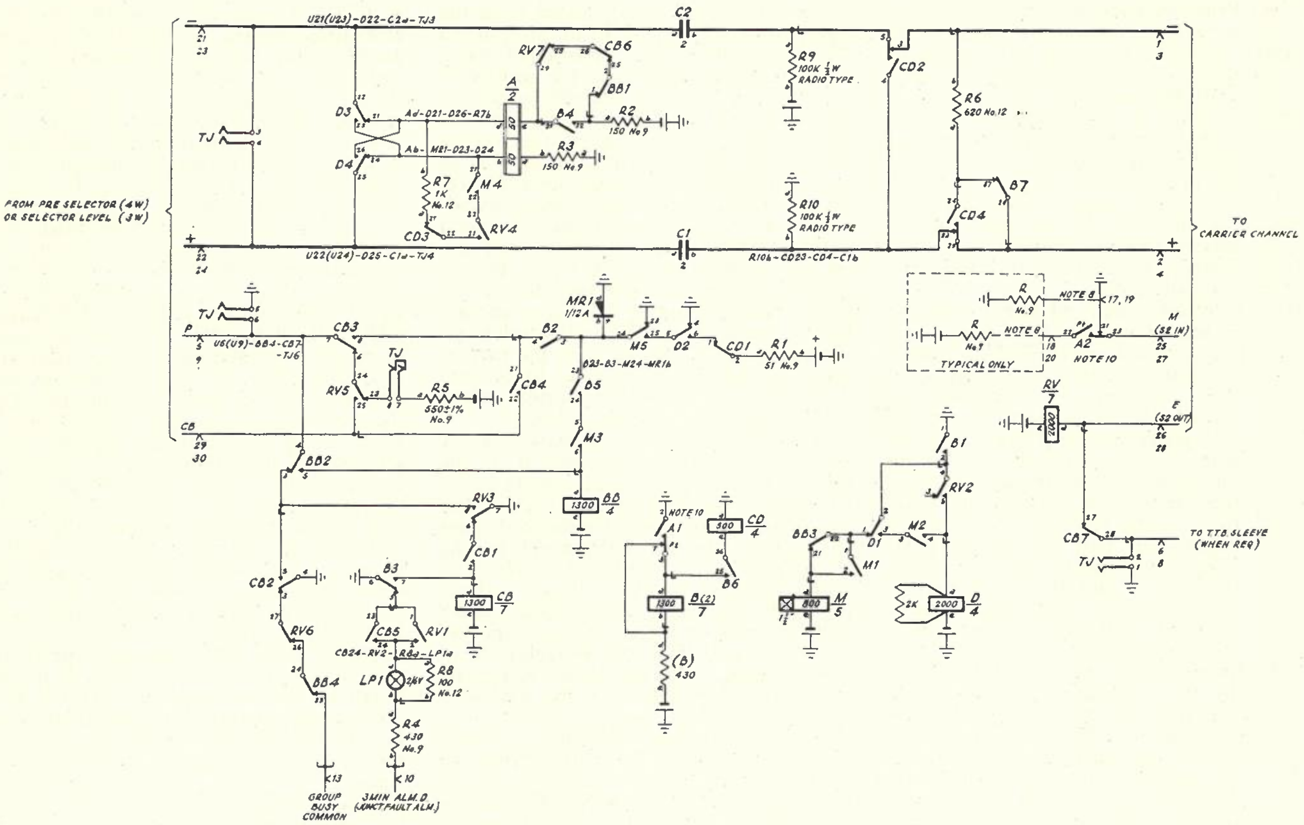

Fig. 6.—Outgoing Signalling Relay Set.

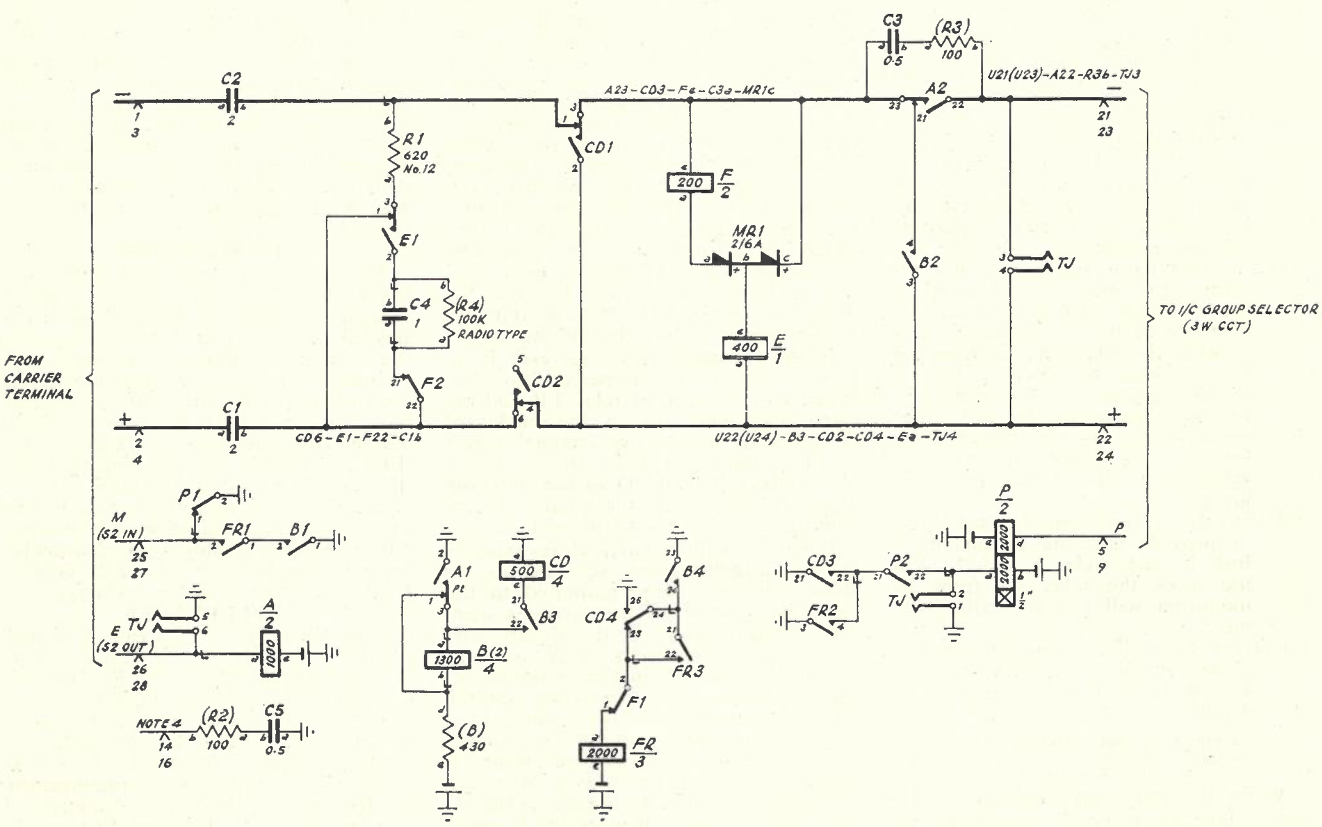

Fig. 7.—Incoming Signalling Relay Set.

(x) Provides back busying should a 2-wire I/C junction be used.
(xi) Provides a 600 ohm termination to the carrier channel under idle and dialling conditions.
(xii) Enables a technician to prebusy without interfering to the release of a call in progress. The delayed alarm is operated after the calling subscriber clears, to ensure that the junction is not held out of service unnecessarily.
(xiii) Enables a technician to hold a call for call tracing.
(xiv) Provides a delayed alarm to bring to attention a junction fault.
(xv) If the carrier system fails in either, or both directions of transmission, the junction is automatically busied due to the use of tone-on-idle signalling conditions and the delayed alarm is operated. When the transmitting direction only of the carrier system fails the junction can be seized by one further caller who will get no progress. When he hangs up he clears from the circuit and the relay set remains busied after the release unguard until the fault condition is cleared.

Incoming Relay Set. Facilities provided by the incoming relay set:—
(i) Provides a termination on the carrier channel under idle conditions. During the setting up of a call the termination is maintained until the called party answers.
(ii) Accepts earth pulses from carrier channel receive signalling lead and repeats loop pulses to automatic exchange selectors.
(iii) When the called party answers a signal is applied to the carrier send signalling lead to repeat the reversal to the outgoing end relay set.
(iv) During release returns a "release guard" signal to busy the outgoing relay set. This release guard is maintained until all the relays in the incoming relay set release and the associated automatic exchange selectors restore to normal.
(v) Provides back busying by not returning the release guard signal to the outgoing relay set should one or more of the —, + or P wires between the relay set and incoming first selector be disconnected or should the first selector not operate for other reasons. The first caller encountering this condition will be lost but on release the outgoing relay set is busied and an alarm given.
(vi) Enables a technician to back busy or provide blocking by placing a link in test jacks 1 and 2. Removal of the relay set from its mounting will automatically back busy.
(vii) Test jacks allow standard impulses to be applied to the relay set input at test jacks 5 and 6 and to be 3 and 4.

CIRCUIT DESCRIPTION

(Refer to Figs. 6 and 7)

When the O/G relay set (Fig. 6) is taken into use, relay A operates to the loop extended from the preceding equipment and earth is disconnected from the signalling send leg (S2 in or M lead) to the static relay. The removal of earth from the send signalling leg results in the static relay being biassed to cut off the signalling tone transmitted over the carrier channel. The signal reeciver at the distant carrier terminal responds to the removal of tone, resulting in the release of the associated high speed signalling relay on the carrier receive signal panel. Contacts of this relay are arranged so that when the relay releases an earth is applied over the receive signalling lead (S2 out or E lead) to operate the A relay in the incoming relay set shown in Fig. 7. Relay A in the incoming relay set extends a loop to operate the associated incoming selector: relays B, FR, E and P operate, also.

When the calling party dials relay A in the outgoing relay set responds to the loop/disconnect pulses and repeats earth/disconnect pulses to the static relay. The pulses of signal tone transmitted over the carrier channel correspond to the break period of the dialled pulses. The signal receiver at the distant carrier terminal responds and extends earth pulses, corresponding to the make period of the callers' dial, to the relay A in the incoming relay set. Relay A repeats loop/disconnect pulses to the exchange equipment.

When the called subscriber answers the reversal of the line polarity from the final selector operates relay F in the incoming relay set. Relay F releases relay FR to remove the earth from the send signalling lead (S2 in) to bias the static relay at the carrier terminal to non-conducting condition and the signalling tone is removed from the carrier channel. The signal receiver at the distant carrier terminal associated with the outgoing relay set responds to the removal of tone and places an earth on the receive signalling lead (S2 out) to operate relay RV in the outgoing relay set. Relay RV operates relay D to complete the positive battery metering circuit to "P" wire and reverses the incoming line potentials to indicate answer supervisory conditions to preceding equipment. Relay M releases to disconnect metering battery and to open the operate circuit of relay M to prevent any further meter pulses during the call.

In the incoming relay set relay F releases when the called party clears followed by operation of relay FR and the signalling conditions in the backward direction of the carrier channel revert to those obtaining when the circuit is idle. Relays RV and D in the outgoing relay set release and the polarity of incoming line restores to normal.

When the calling party clears relay A in the outgoing relay set releases resulting in tone being reapplied to the signalling channel of the carrier system. The signal receiver at the distant carrier terminal restores to the normal condition and relay A in the incoming relay set releases. This opens the holding circuit of relay B and the holding loop to the incoming selector equipment which commences to release. Relay B releases followed by release of relays FR and P. When relay B releases the release guard signal comences and is maintained until relay P releases. Relays A, B, CD, FR, and P release in sequence and thus ensure a minimum release guard period to cover necessary circuit operations in the outgoing relay set should the selectors at the incoming exchange restore to normal quickly. The release guard is maintained until relay P releases, that is, for the period of release of relays CD, FR and P. When relay B releases in the outgoing relay set, relay CB remains operated via normal contact of RV and maintains an engaged condition on the P wire. At the outgoing relay set the release guard signal operates relay RV and releases relay CB. Relay RV remains operated to guard the outgoing relay set until the incoming relay set and selectors at the distant exchange restore to normal. On the termination of the release guard signal relay RV in the outgoing relay set restores to normal and removes engaged condition from the "P" wire. All equipment has now restored to normal and is free to accept another call.

Should the calling party clear first, the answer supervisory condition returned from the incoming relay set is maintained and merges with the release guard signal. In this case, as relay RV in the outgoing relay set is operated prior to clear down, the release of relay B in the outgoing relay set releases relay CB and the engaged condition on the private will be maintained until relay RV releases on termination of the release guard signal.

When a release guard signal is not returned during release of the junction, relay CB in the outgoing relay set is left locked up to maintain a guarding earth on the "P" wire of the outgoing relay set. The release guard is not given when a fault condition exists on the transmitting side of the carrier system resulting in the incoming relay set not being seized. The same applies when there is a fault on the incoming exchange equipment. In each case the first call is lost but the junction is busied to subsequent calls and automatically restored to service when the fault condition has been cleared.

CONCLUSION

The relay sets described have been installed and are working on all carrier junctions linking the Melbourne metropolitan area via City West exchange to the sub-metropolitan automatic exchanges. Suitable circuit guards for back busying and elimination of no progress have been provided. The relay sets are suitable for signalling over carrier junctions provided by systems employing out of channel signalling facilities. The incoming relay set is suitable also for use at the incoming end of a multimetering trunk channel employing a multimetering relay set in accordance with drawing CE.11017 at the outgoing exchange.

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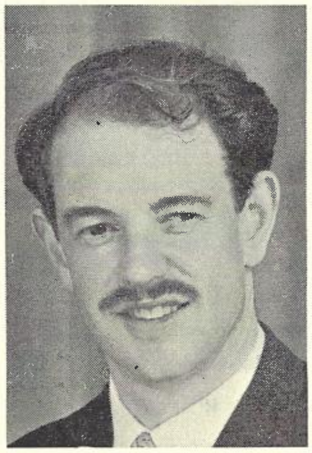
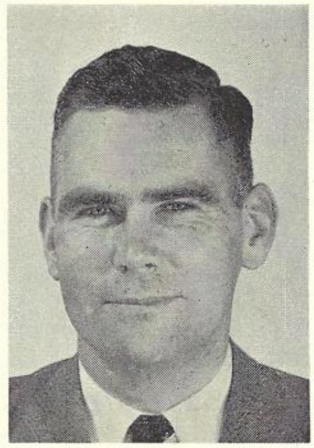


H. S. WRAGGE



D. P. BRADLEY

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For many years Mr. O'Grady has shown a keen interest in the Journal and has contributed a number of articles to it. He is at present Chairman of the Council of Control of the Society. It is a source of gratification to all concerned with the Journal that Mr. O'Grady, despite his heavy administrative responsibilities any many other commitments, is still a regular author of articles.

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★

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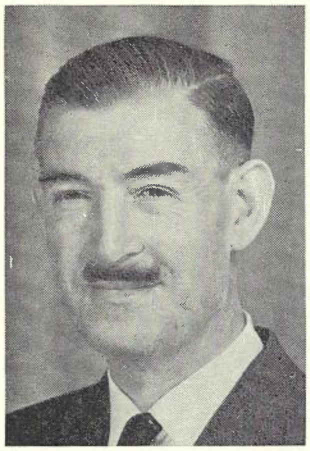
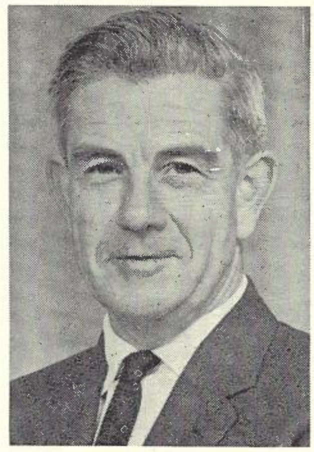
Mr. Kitchenn is Chairman of the Headquarters Trunk Planning Co-ordination Committee, and has been Secretary of the Postal Electrical Society of Victoria (later Telecommunication Society of Australia) since 1958. He holds the London degree of Bachelor of Science (Engineering) and is an Associate Member of the I.E.E. (1946) and of the Brit. I.R.E. (1947).



R. G. KITCHENN

L. A. WHITE



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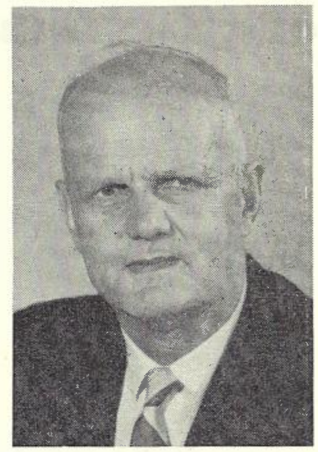

E. J. BULTE

L. A. WHITE, author of the article "Carrier Junction Signalling Relay Sets", joined the Department in 1942 as a Junior Mechanic. In 1951, he qualified as an Engineer and has since worked in the Long Line and Country Installation Section of the Country Branch, Victoria, where he has been responsible for many telephone exchange and carrier system installations of various types. He was in charge of the installation of the Dandenong automatic exchange and associated trunk exchange which was put into service on 1st May, 1960, co-incident with the implementation of E.L.S.A.

Mr. White has acted as Divisional Engineer since 1957 and is Circuit Liaison Officer for the Country Branch, Victoria.

★

J. W. POLLARD, author of the article "Application of Gas Pressure Alarm Systems to Coaxial Cables", joined the Department in 1927 as a Cadet Engineer. He graduated Bachelor of Science at the University of Melbourne in 1930 and qualified as an Engineer in 1931. After experience in the Victorian Transmission and Lines Sections he was transferred in 1942 to the Lines Section at Central Office. His present position is Divisional Engineer in charge of cable maintenance.

Mr. Pollard has been a sub-editor of the Journal since 1944 and was Treasurer of the Postal Electrical Society of Victoria for three years. Early this year he was elected a Life Member of the Telecommunication Society of Australia. He is an Associate Member of the Institution of Engineers, Australia.

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E. J. BULTE, author of the article "Automatic P.G. Alarms for Indication of Cable Faults", is Supervising Engineer, Metropolitan Service, Melbourne. He joined the Department as a Cadet Engineer in 1927 and qualified as Engineer in 1932. He qualified for the degree of Bachelor of Science at the Melbourne University. After a period of seven years, divided about equally on external and internal plant in the Melbourne Administration, he transferred to the Engineer-in-Chief's office, where he was engaged for a period of twenty years, mostly in the Telephone Equipment Section, but including several years at the Research Laboratories. He transferred back to the Victorian Administration two years ago.

Mr. Bulte was a member of the Board of Editors of this Journal from 1956 to 1959, a Past-President of the Society, and is at present Sub-Editor for Victoria. He is a Councillor of the Victorian Division of the Australian Postal Institute and a trustee of the Victorian Branch of the Professional Officers' Association.

ANSWERS TO EXAMINATIONS

Examination No. 4736—4th July, 1959 and subsequent dates.

TO GAIN PART OF THE QUALIFICATIONS FOR PROMOTION OR TRANSFER AS SENIOR TECHNICIAN, TELEPHONE, POSTMASTER-GENERAL'S DEPARTMENT, ALL STATES

PART I

QUESTION 1.

(a) Draw the simple schematic circuit of a 300 type telephone in the dial off normal condition.

(b) What is the purpose of the 600 ohm non-inductive resistor in series with the capacitor connected across the tip and ring of the cord circuit of the standard lamp signalling P.B.X. during a certain stage of a call?

(c) How are acoustic shocks reduced in the operator's circuit of a lamp signalling P.B.X.?

(d) On a local call in a 2,000 type exchange the calling subscriber clears but the called subscriber does not; which switches in the train are released and how is this condition achieved? Circuit descriptions are not required.

(e) What is meant by the term "grade of service"?

ANSWER 1 (E. CULPH).

(a)

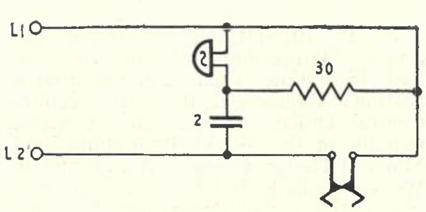

Fig. 1.

(b) The purpose of the 600 ohm resistor and the $2\mu F$ Capacitor is to prevent a possible unbalanced termination to incoming trunk lines equipped with amplifiers.

The resistor and capacitor in series provide an Audio or Voice Frequency termination across the cord circuit during switching to the extension when neither the telephonists circuit (K.S. Released) or the extension telephone (before "B" relay operates) is across the incoming trunk line.

(c) By connecting two metal rectifiers across the telephonist's receiver as shown

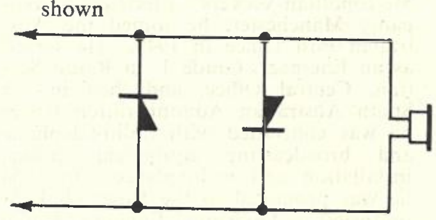

Fig. 2.

The metal rectifiers connected in this manner offer a high impedance in both directions to the low voltage speech currents and a low impedance shunt path to the inductive surges, thus by-passing the receiver.

(d) When the calling party clears, removal of the earth on the "P" wire releases all switches preceding the final selector. The final selector is held operated to the called subscriber's loop, and an earth applied to the "P" wire to re-guard the final selector.

(e) Grade of service is a measure of the service given from the point of view of sufficiency of plant. It can be expressed as the proportion of the number of calls which are allowed to fail during the busy hour due to the lack of switching plant.

QUESTION 5.

(a) List in their correct order the tests you would apply to a new subscriber's service in underground cable assuming no fault conditions are revealed during the tests.

(b) Show by a simple circuit diagram the circuits used to perform the following tests on a subscriber's line from a Test Desk. Value of resistors, meter, etc., in the test circuits is not required, but voltage of testing battery and the keys operated should be shown.

(i) Line resistance, low scale.

(ii) Capacity test.

ANSWER 5 (E. CULPH).

(a) (i) Resistance.

(ii) Capacity.

The minimum allowable insulation resistance for a subscriber's line is 0.5 Megohm, and the normal condenser kick is about 70 scale divisions. If the resistance and the capacity tests are satisfactory no tests for earth or foreign battery are necessary.

(iii) The subscriber's telephone is rung and the low resistance test applied to measure the loop resistance.

(iv) The testing officer checks the transmission performance of the subscriber's service by listening with the 25 db and the 40 db pads in circuit.

(v) Dial impulse weight test.

(vi) Dial impulse speed test.

(vii) Impulse count test.

(viii) Test for correct polarity of line relay and connections.

(ix) Test for dial tone and make a test call through the exchange apparatus using the Test Desk Telephone circuit.

(x) Correct operation of subscriber's meter.

(b) (i) Line resistance, low scale.

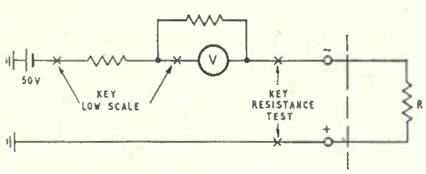

Fig. 3.

(ii) Capacity.

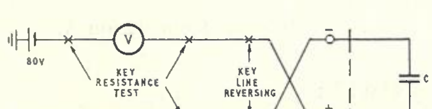

Fig. 4.

QUESTION 6.

Briefly answer each of the following questions:—

(a) What is the purpose of an isthmus relay armature and give an example of its use?

(b) (i) What is meant by the letter C on the cheek of a 3,000 type relay?

(ii) List two other items of information in addition to that mentioned in (i) that are shown on the cheek of a 3,000 type relay.

(c) What are the three important adjustments to be made on a Siemens high speed relay having a single changeover contact?

(d) List three features which contribute to the high speed of operation of a Siemens high speed relay.

(e) What is the approximate operate time of a Siemens high speed relay?

ANSWER 6 (D. KENNER).

(a) Isthmus armatures are used on impulsing relays on group selectors, final selectors, discriminating selector repeaters, repeater relay sets and other equipment which must respond to dialled impulses.

The shape of the isthmus armature, by allowing saturation at a low flux value, helps in obtaining a constant response from the relay when operating and releasing on various lengths of line. The reduced weight also allows a slightly faster operation of the relay.

(b) (i) The letter "C" is used to indicate that the armature should have a fixed residual stud with a nominal length of 20 mils.

(ii) The colour of the label (white or green) indicates the thickness of the relay springs and the pressure applied by each spring. A red label indicates that the relay is a special relay and the individual adjustments for that relay must be obtained from an adjustment chart. An "X" or "Y" on the cheek indicates that the relay springsets contain an "X" or "Y" unit.

(c) (i) Set the make contact screw so that it just touches the moving contact when the armature is held operated. Then turn the screw a further quarter of a turn to provide a residual air gap. Tighten the locking screw.

(ii) Adjust the break contact so that a 4 mil gauge will just pass between the make and moving contact.

(iii) Turn the tension screw until the break contacts can be opened with from 15 to 20 gram pressure when applied to the tip of the armature spring. Use a meter or a lamp to determine when the contacts close.

(d) The three main features which allow a high speed of operation are:—

(i) a low inductance winding,

(ii) a short armature travel.

(iii) a moving system of small mass.

(e) The operate time of these relays may vary from 0.5 milliseconds to 1.5 milliseconds, with an average time of approximately 1 millisecond.

The answers given to questions 6c, d and e are based on the references indicated for the 1959 examination.

PART II

QUESTION 9.

A transmission measuring set calibrated to read power in decibels relative to 1 milliwatt in 600 ohms has a high input impedance.

In the absence of a meter specially calibrated for 150 ohm circuits, it is terminated with a 150 ohm resistor and used to measure the power output from an amplifier designed to operate with a load of 150 ohms.

If a meter reading of +24 db is obtained, what is the power in milliwatts dissipated in the 150 ohm resistor terminating the meter.

For the purposes of calculation the following figures may be used—

$$Log_{10}2 = 0.3.$$

$$Antilog_{10}0.2 = 1.6.$$

ANSWER 9 (S. GALE)

When 1 mW is dissipated in 600 ohms, the voltage

$$E_1 = \sqrt{PR}$$

$$= \sqrt{\frac{1}{1000} \times \frac{600}{1}} = \sqrt{0.6} \text{ volt.}$$

Therefore, the T.M.S. is calibrated to read 0 db when $\sqrt{0.6}$ volt is applied.

To find voltage (E) which gives T.M.S. reading of +24 db:

$$db = 20 \log \frac{E}{E_1}$$

$$24 = 20 \log \frac{E}{\sqrt{0.6}}$$

$$1.2 = \log \frac{E}{\sqrt{0.6}}$$

$$\text{antilog } 1.2 = \frac{E}{\sqrt{0.6}}$$

but antilog 1.2 = 16

$$\therefore \quad 16 = \frac{E}{0.6}$$

$$E = 16 \sqrt{0.6} \text{ volts}$$

$\therefore$ Power

$$\text{in 150 ohm resistor} = \frac{E_2}{R}$$

$$= \frac{16\sqrt{0.6} \times 16\sqrt{0.6}}{150} \text{ watts}$$

$$= \frac{16 \times 16 \times 0.6 \times 1000}{150} \text{ mW}$$

Answer = 1024 mW.

ANSWER 9. (Alternative Solution).

Let voltage applied to meter = E then apparent power

$$= +10 \log \frac{E^2}{600} \text{ dbm}$$

and true power

$$= +10 \log \frac{E^2}{150} \text{ dbm}$$

$\therefore$ error

$$= \left[10 \log \frac{E^2}{150} - 10 \log \frac{E^2}{600}\right] \text{ db low}$$

$$= 10 \log \frac{E^2/150}{E^2/600}$$

$$= 10 \log \frac{600}{150}$$

$$= 10 \log 4$$

$$= 6 \text{ db low}$$

$$\therefore \text{ true level} = +24 \text{ dbm} + 6 \text{ db}$$

$$= +30 \text{ dbm}$$

ANSWER $= 1000$ mW

QUESTION 11.

You have just completed the installation of one terminal of a modern three channel carrier telephone system having copper oxide modulators, feedback amplifiers and crystal oscillators.

(a) List the tests which you would carry out to ensure that the terminal is in good working order so that line-up may proceed. You are not required to carry out the overall system line up. Details of how the tests should be carried out are not required.

(b) List the testing instruments which would be essential to completion of your initial testing.

ANSWER 11 (E. CULPH).

(i) Check all power supply voltages.
(ii) Insert all fuses.
(iii) Insert all electron tubes.
(iv) Adjust filament currents.
(v) Check anode currents.
(vi) Check alarm circuits.
(vii) Transmission tests—
   (a) Terminate hybrids and carrier line in 600 ohms with variable equalisers out of a circuit.
   (b) Check modulator and demodulator oscillator supplies to modulators and demodulators. Adjust as required.
   (c) Adjust carrier leak to a minimum.
   (d) Check gains and losses in transmit direction.
   (e) Check gains and losses in receive direction.

(b) Voltmeter, Ammeter, Milliammeter } or suitable Multimeter
Audio frequency oscillator
Carrier frequency oscillator
Transmission Measuring Set (TMS)
Attenuators
600 ohm terminations.

QUESTION 13.

(a) Draw a block schematic diagram of the channelling equipment of any 12 channel cable or open wire carrier telephone terminal.
Show the main items of equipment associated with each channel from the two wire voice frequency terminals to the carrier frequency common connection of the band filters. Inclusion of group equipment is not required, but sub-group equipment should be shown if it forms part of the system chosen.
Signalling equipment need not be shown.
Connection of carrier supplies to channel modulators and demodulators and to sub-group equipment if included should be shown.

(b) State the limits of the frequency band occupied by the 12 channel group at the output of the channel bank. Specify the nominal values of the impedance and level at this point.

ANSWER 13 (D. KENNER).

(a)

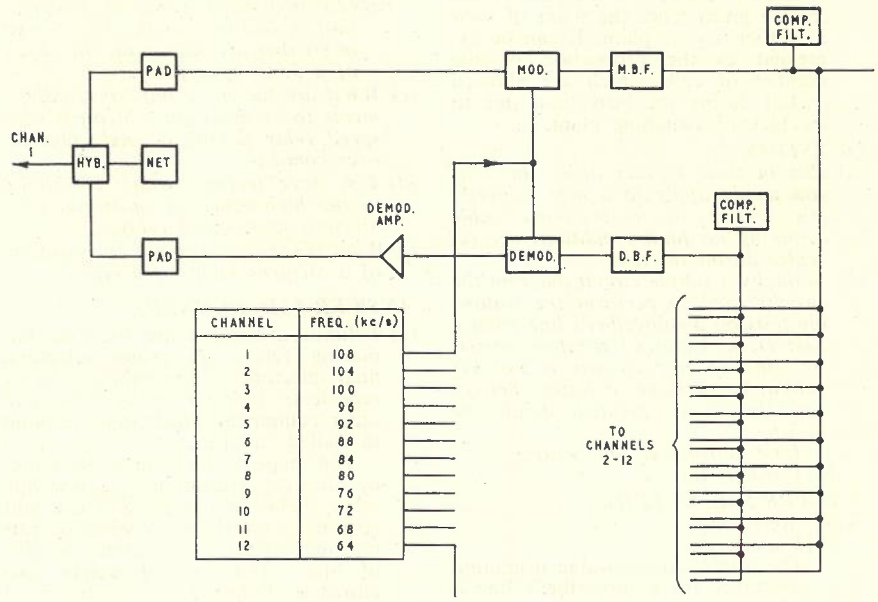

Fig. 5.

(b) Frequency band limits 60–108 Kc/s.
Nominal impedance 135 ohms.
Level − 42 db. Transmit
− 5 db. Receive.

QUESTION 14.

You are required to locate by bridge methods an earth fault on a section of open wire line 100 miles long having a loop resistance of 880 ohms. There is no entrance cable at either end of the circuit.

Preliminary voltmeter measurements have shown that the insulation resistance between wires and to earth is low and that the fault resistance is high relative to the insulation resistance. Under these circumstances the normal varley measurement gives a wrong result and the double varley must be used.

The calculated value of the single wire resistance to the fault from the A station, using the normal varley formula, exceeds the true value by an amount equal to

$$\frac{R_A}{2}\left[\frac{L-Y}{Y}\right] \text{ where}$$

R_A = The varley bridge reading at the A station
L = The loop resistance.
Y = The sum of the varley readings at A and B stations.

If in this case the varley reading at your station (station A) is 490 ohms and the reading at the distant station B is 210 ohms –

(a) Find the true location of the fault.

(b) How far from the fault would a Lineman be if he were despatched to a location determined from a varley measurement made at your station only?

ANSWER 14 (S. GALE).

Single wire res.
= 880 ohms for 200 miles.
= 4.4 ohms/mile.

For normal varley with equal ratio arms,

$$X = \frac{L - R}{2}$$

where X = resistance (ohms) of faulty wire from testing
L = loop resistance (ohms)
R = varley reading (ohms)

$$\therefore X = \frac{880 - 490}{2} = 195 \text{ ohms}$$

Calculated dist. to fault

$$= \frac{\text{Res. of faulty wire (X)}}{\text{Wire resistance/mile}}$$

$$= \frac{195}{4.4} = 44.3 \text{ miles from station A.}$$

But this value of X exceeds true value by

$$\frac{R_A}{2}\left[\frac{L-Y}{Y}\right] = \frac{490}{2} \times \frac{880 - 700}{700}$$

$$= \frac{490}{2} \times \frac{180}{700} = 63 \text{ ohms}$$

$\therefore$ True value of X = 195 − 63.

$\therefore$ True dist. to fault

$$= \frac{132}{4.4} = 30 \text{ miles from station A.}$$

ANSWER:

(a) 30 miles from station A.
(b) 14.3 miles (approx.).

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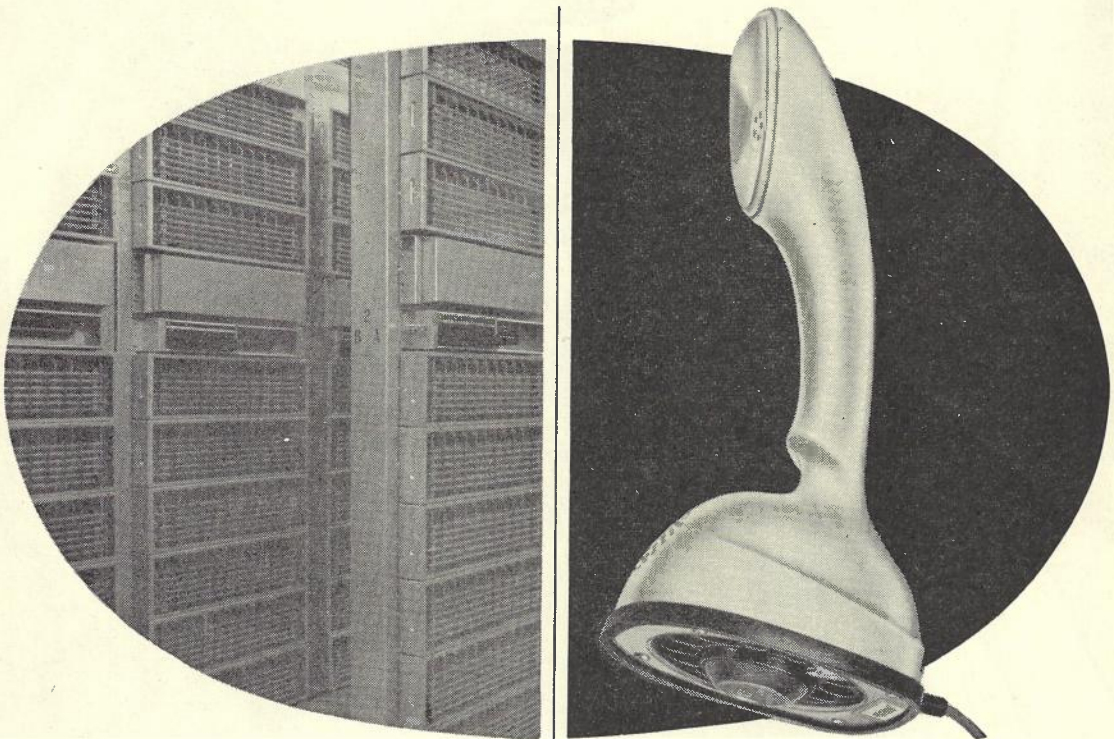

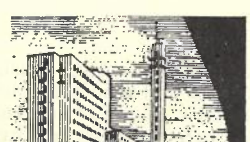

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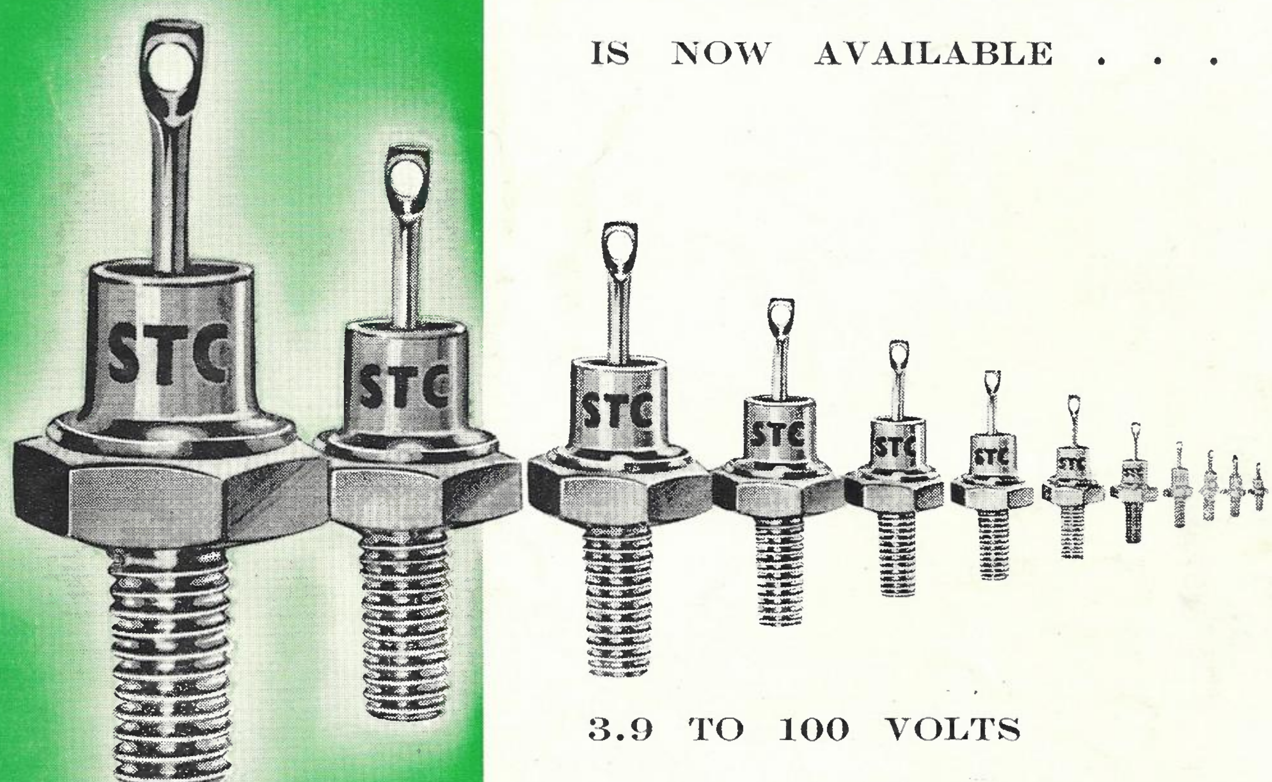

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